JSC-08457

NASA TECHNICAL MEMORANDUM

NASA TM X-58118

July 1974

ORIGINAL CONTAINS COLOR ILLUSTRATIONS

NOV 1974 RECEIVED NASA STI FACILITY ACQ BRANCH

(NASA-TM-X-58118) THE ERTS-1 INVESTIGATION (ER-600). VOLUME 2: ERTS-1 COASTAL/ESTUARINE ANALYSIS Report for period Jul. 1972 - Jun. 1973 (NASA) 286 p HC $8.75 CSCL 08J G3/43 N75-13371 Unclas 03525

THE ERTS-1 INVESTIGATION (ER-600)

VOLUME II — ERTS-1 COASTAL/ESTUARINE ANALYSIS

(REPORT FOR PERIOD JULY 1972 - JUNE 1973)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TEXAS 77058

DEC 1974 RECEIVED NASA STI FACILITY INPUT BRANCH

NASA TM X-58118

THE ERTS-1 INVESTIGATION (ER-600)

VOLUME II — ERTS-1 COASTAL/ESTUARINE ANALYSIS

(REPORT FOR PERIOD JULY 1972 - JUNE 1973)

R. Bryan Erb
Lyndon B. Johnson Space Center
Houston, Texas

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

1. Report No. NASA TM X-58118	2. Government Accession No.	3. Recipient's Catalog No
4. Title and Subtitle THE ERTS-1 INVESTIGATION (ER-600): VOLUME II — ERTS-1 COASTAL/ESTUARINE ANALYSIS (REPORT FOR PERIOD JULY 1972-JUNE 1973)		5. Report Date July 1974 6. Performing Organization Code
7. Author(s) R. Bryan Erb		8. Performing Organization Report No JSC-08457 10. Work Unit No. 641-14-07-50-72
9. Performing Organization Name and Address Lyndon B. Johnson Space Center Houston, Texas 77058		11. Contract or Grant No. 13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		14. Sponsoring Agency Code

15. Supplementary Notes

The JSC Director waived the use of the International System of Units (SI) for this Technical Memorandum because, in his judgment, the use of SI Units would impair the usefulness of the report or result in excessive cost.

16. Abstract

The Coastal Analysis Team of the Johnson Space Center conducted a 1-year investigation of ERTS-1 MSS data to determine its usefulness in coastal zone management. Galveston Bay, Texas, was the study area for evaluating both conventional image interpretation and computer-aided techniques.

There was limited success in detecting, identifying and measuring areal extent of water bodies, turbidity zones, phytoplankton blooms, salt marshes, grasslands, swamps, and low wetlands using image interpretation techniques. Computer-aided techniques were generally successful in identifying these features. Aerial measurement of salt marshes accuracies ranged from 89 to 99 percent. Overall classification accuracy of all study sites was 89 percent for Level I and 75 percent for Level II.

17. Key Words (Suggested by Author(s)) ·Wetlands ·Phytoplankton ·Turbidity	18. Distribution Statement STAR Subject Category:13

19. Security Classif (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No of Pages 284	22. Price

PREFACE

This report is one of seven separate reports prepared by six discipline-oriented analysis teams of the Earth Observations Division at the Lyndon B. Johnson Space Center, Houston, Texas.

The seven reports were prepared originally for Goddard Space Flight Center in compliance with requirements for the Earth Resources Technology Satellite (ERTS-1) Investigation (ER-600). The project was approved and funded by NASA Headquarters in July 1972.

This report (Volume II) was accomplished by the Coastal Estuarine Analysis Team. The following is a list of the team members.

J. F. Paris, Lockheed Electronics Company, Inc. (Team Leader)

L. M. Flores, Lockheed Electronics Company, Inc.

S. B. Hixon, Lockheed Electronics Company, Inc.

C. A. Reeves, Lockheed Electronics Company, Inc.

R. J. Thoben, National Aeronautics and Space Administration

E. A. Weisblatt, Lockheed Electronics Company, Inc.

J. B. Zaitzeff, National Oceanic and Atmospheric Administration

PRECEDING PAGE BLANK NOT FILMED

Volume	Title	NASA Number
I	ERTS-1 AGRICULTURAL ANALYSIS	TM X-58117 JSC-08456
II	ERTS-1 COASTAL/ESTUARINE ANALYSIS	TM X-58118 JSC-08457
III	ERTS-1 FOREST ANALYSIS	TM X-58119 JSC-08458
IV	ERTS-1 RANGE ANALYSIS	TM X-58120 JSC-08459
V	ERTS-1 URBAN LAND USE ANALYSIS	TM X-58121 JSC-08460
VI	ERTS-1 SIGNATURE EXTENSION ANALYSIS	TM X-58122 JSC-08461
VII	ERTS-1 LAND-USE ANALYSIS OF THE HOUSTON AREA TEST SITE	TM X-58124 JSC-08463

CONTENTS

TABLES

FIGURES

ABBREVIATIONS AND ACRONYMS

CCT	computer-compatible tape
CRT	cathode-ray tube
DAS	data analysis station
DLMIN	separability parameter (refer to pg. 8-9)
ERIPS	earth resources interactive processing system
ERTS	Earth Resources Technology Satellite
G.m.t.	Greenwich mean time
GSFC	Goddard Space Flight Center
ISOCLS	(refer to footnote 1, pg. 1-5)
ISTOP	maximum number allowable iterations (refer to pg. 8-9)
JSC	Lyndon B. Johnson Space Center
LARSYS	(refer to footnote 2, pg. 1-5)
l.s.t.	local standard time
MAXCLS	maximum number clusters to be defined (refer to pg. 8-9)
MCFV	multiband camera film viewer
MSDS	multispectral data system
MSS	multispectral scanner system
NSCLAS	(refer to footnote 3, pg. 1-6)
PMIS	passive microwave imaging system
RBV	return beam vidicon
ROTAR	reconstruction of target radiance
STDMAX	maximum allowable standard deviation (refer to pg. 8-9)

THE ERTS-1 INVESTIGATION (ER-600)

VOLUME II - ERTS-1 COASTAL/ESTUARINE ANALYSIS

(REPORT FOR PERIOD JULY 1972 - JUNE 1973)

By R. Bryan Erb
Lyndon B. Johnson Space Center

1.0 SUMMARY

1.1 OBJECTIVE AND SCOPE

The sensor applications performance of the first Earth Resources Technology Satellite (ERTS-1) was evaluated to determine its ability to acquire information useful for coastal zone management. The evaluation included the detectability and areal measurement accuracy attainable for selected coastal study features, as well as the determinations of the spectral uniqueness and temporal properties of these features. Only multispectral scanner (MSS) system-corrected data were evaluated.

The subject coastal features are listed in figure 1-1 in a hierarchy of Level I, II, and III categories. The hierarchy is not exhaustive, but shows only those features chosen for this coastal investigation.

The primary basis for the ERTS-1 evaluation of the location, identification, and areal extent of these features in the study sites was the aircraft photography collected over the study area during ERTS-1 passes. These data were supplemented by field checks.

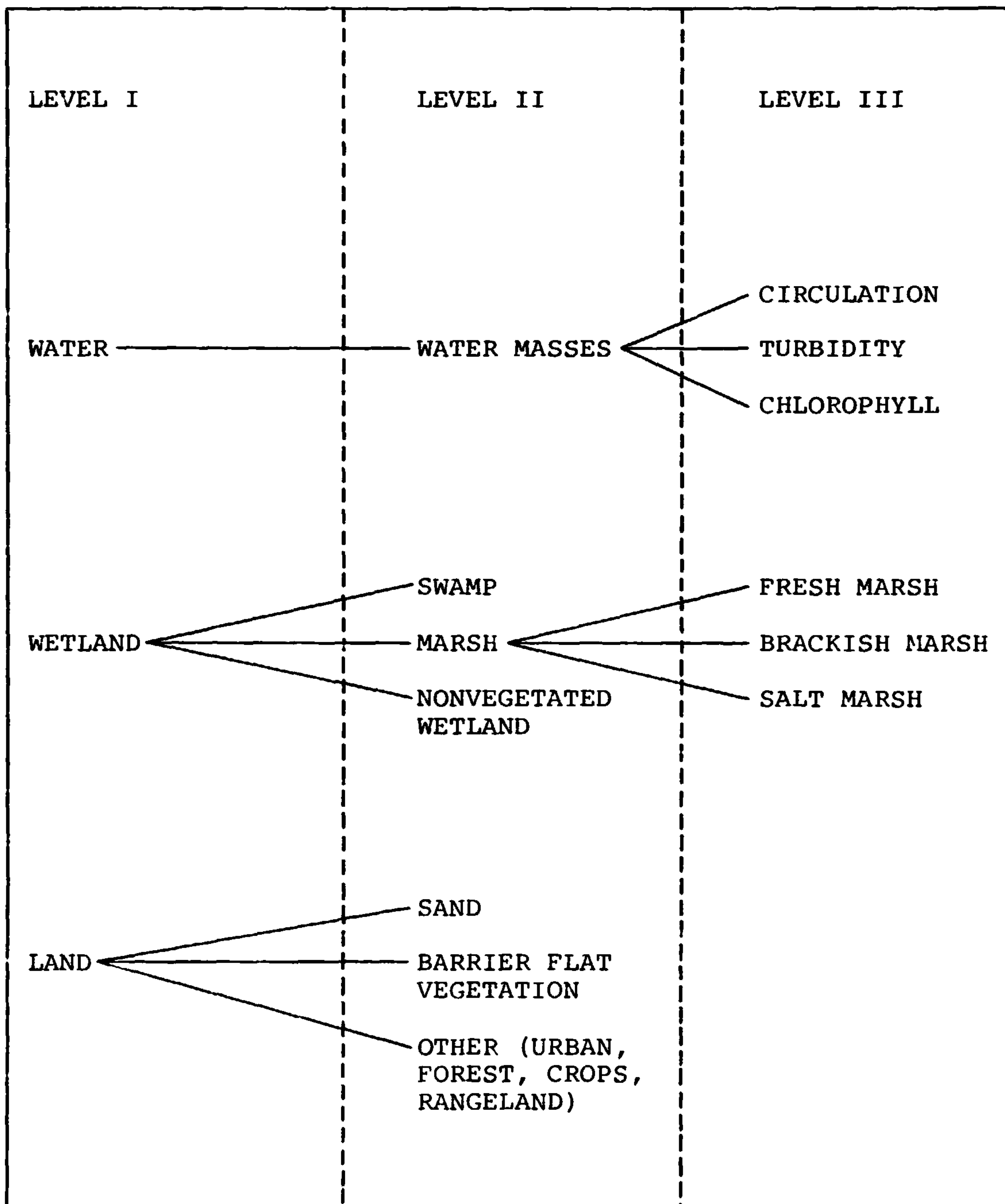


Figure 1-1.- Feature hiera[illegible]y for coastal investigation.

The study area was a portion of Galveston Bay, Texas, that was imaged on two consecutive passes of the ERTS-1 every 18 days. The three sites selected in the study area included all subject study features.

1.2 APPROACH

Three ERTS-1 data sets were processed by computer-aided means and evaluated (section 8.0). These sets were acquired August 28 and 29, October 3, and November 26, 1972. Two computer-aided techniques were used. The first was an unsupervised maximum likelihood classification technique. Atmospheric, calibration, and sun-angle correction techniques were used to obtain reflectance signatures of coastal features for the ERTS-1 spectral bands.

Several sets of ERTS-1 film data were processed by conventional photointerpretive and additive multiband color techniques (section 7.0). The data sets analyzed in this manner were acquired by ERTS-1 over the study area August 28 and 29, October 3, and November 26, 1972, as well as January 19 and February 24, 1973.

1.3 RESULTS AND CONCLUSIONS

Concurrent measurements of water surface turbidity (ppm) and water reflectance measurements with a four-band radiometer with passbands similar to ERTS-1 showed that the water reflectances in MSS band 4 (λ 500 to 600 nm) and band 5 (λ 605 to 700 nm) were highly correlated with turbidity (correlation coefficient was about 0.9). Also, the infrared reflectance of water increased with turbidity for highly turbid water (> 50 ppm). In addition, the peak reflectance shifted from green to red for increasing water turbidity ($\sim$ 100 ppm).

The detectability of coastal features varied with type of processing as shown in table 1-I.

The attempts to map coastal features from ERTS-1 MSS system-corrected film data resulted in limited successes. Water bodies, water turbidity zones, phytoplankton blooms, salt marshes, grasslands, forest, and sand/urban areas were detected and mapped in all of the film data. Oil/waste pollution, swamp, fresh and brackish marshes, and nonvegetated wetland could not be detected and mapped from film data with consistency. These results were based on fourth- and fifth-generation film products.

The attempts to map coastal features from ERTS-1 MSS system-corrected computer-compatible-tape (CCT) data were successful in general. Water bodies, water turbidity zones, wetlands, fresh, brackish, and salt marshes, nonvegetated wetlands, algal mats, swamps, land, sand, dry grasslands, forest, pine forest, mixed pine, and hardwood forest, major roads, urban areas, major bridges, and flooded rice fields were detected and mapped in all processed CCT data with consistency. Oil/waste pollution was detected on one occasion only as the misclassification of a known water area as salt marsh.

The results of the unsupervised ISOCLS[1] clustering products were more accurate and generally more suitable in mapping coastal features than were the products of the

[1]NASA Johnson Space Center clustering algorithm.

TABLE 1-I.- DETECTABILITY OF COASTAL FEATURES IN PROCESSED ERTS-1 IMAGERY

Feature	Data Type					
	GFSC B&W 240-mm pos. transparencies	MCFV analog color composite	MCFV digital additive color	DAS color composites	Cluster analyses	Maximum likelihood classification
Water	A	A	A	A	A	A
Turbidity Zones	A	A	A	A	A	A
Phytoplankton Blooms	A	-	-	-	-	-
Waste/Oil Pollution	N	N	N	S	S	-
Wetlands	S	S	S	S	A	A
Swamp	S	S	S	S	A	S
Marsh	S	S	S	S	A	S
Fresh Marsh	N	N	S	N	A	S
Salt Marsh	A	A	S	A	A	A
Vegetal Assemblages	N	N	N	N	A	S
Nonveg. Wetland	N	S	S	A	A	A
Algal Mats	N	N	N	N	A	-
Land	S	S	S	A	A	A
Sand	S	S	S	A	A	A
Barrier Flat Veg.	S	A	A	A	A	A
Vegetal Assemblages	N	N	N	N	S	-
Forest	A	A	A	A	A	A
Pine	N	N	N	S	A	-
Hardwoods	N	N	N	S	A	-
Roads (concrete)	A	A	A	A	A	-
Bridges (concrete)	S	S	S	S	S	-
Urban	S	S	S	S	S	-
Rice fields	S	S	S	S	S	-

A – always detected
S – sometimes detected
N – never detected
- – not evaluated

supervised LARSYS[2] maximum-likelihood classification. This was due to the spectral heterogeneity of the coastal features on the ERTS-1 scale; this suggests that the difficult problem of training field selection in heterogeneous areas might best be solved by some combination of clustering and supervised classification. The overall classification accuracies for the ISOCLS and LARSYS computer-aided processing products are given in tables 1-II and 1-III for selected test fields.

The accuracies of the areal measurement of water bodies and salt marsh areas were high, based on the unsupervised clustering analyses of ERTS-1 CCT data. By counting subject picture elements and portions of boundary picture elements identified from the unsupervised clustering products, the areal extent of three salt marsh areas and 19 water bodies was determined from the ERTS-1 data. The two clustering algorithms used were ISOCLS and NSCLAS.[3] Comparison of the areal extent of these areas as obtained from the aircraft photography showed that (1) the accuracy of salt marsh areal measurements ranged from 89 to 99.8 percent (see table 1-IV), and (2) the error in estimating water body size was 2.0 hectares and was independent of the size of the water body (see table 1-V).

When the spectral uniqueness of coastal features in the ERTS-1 spectral bands was evaluated, the Levels I and II features were found to be represented by a family of spectral reflectance curves. In the case of water, swamp, marsh, nonvegetated wetland, sand, dry marshland, and forest, there

---

[2]Maximum likelihood classification algorithm developed at Laboratory for Applications of Remote Sensing, Purdue University.

[3]Purdue University clustering algorithm.

TABLE 1-II.- OVERALL CLASSIFICATION OF ALL STUDY SITES, ALL DATES, USING ISOCLS

Test Field	Water	Swamp	Marsh	Nonveg Wetland	Sand	Veg	Other	% Correct Level I**	% Correct Level II***
Water	2972*	0	0	0	0	0	0	100.0	-
Swamp	10	277	215	3	0	0	109	80.1	45.1
Marsh	34	104	1233	2	1	2	457	72.9	67.3
Vegetation	0	0	22	0	0	489	7	95.8	94.4
Other	1	3	16	12	24	31	906	96.8	91.2
							Overall Average	89.1	74.5

*Number represent number of picture elements in a given test field that were classified as a given feature.

**Level I accuracies were computed by considering any Level I feature classification that was in the same category as the test field as being correct.

***Level II accuracies were computed by considering only those picture elements classified as belonging to the given test field type as being correct.

TABLE 1-III.- OVERALL CLASSIFICATION ACCURACY OF ALL STUDY SITES AND DATES USING LARSYS

Test Field	Water	Swamp	Marsh	Nonveg Wetland	Sand	Veg	Other	Threshold	% Correct	
									Level I**	Level II***
Water	912*	6	80	0	0	0	0	30	88.1	-
Swamp	0	298	68	0	1	0	18	27	88.8	72.3
Marsh	10	22	628	2	10	0	53	111	78.0	75.1
Nonveg Wetland	0	0	0	134	26	0	0	13	77.5	77.5
Vegeta-tion	3	0	0	7	10	148	4	22	83.5	76.3
Other	0	65	18	0	23	51	820	102	82.9	76.0
								Overall Average	83.2	75.4

*See footnote in Table 1-II
**See footnote in Table 1-II
***See footnote in Table 1-II

TABLE 1-IV.- RESULTS OF AREAL MEASUREMENT OF SALT MARSH AREAS IN GALVESTON STUDY SITE IN AUGUST 1972

Marsh	Area (hectares)			% Accuracy	
	Aircraft	ISOCLS	NSCLASS	ISOCLS	NSCLASS
1	351.	350.	353.	99.8	99.4
2	77.4	79.6	76.6	97.0	99.
3	60.5	60.9	67.1	99.2	89.

TABLE 1-V.- RESULTS OF AREAL MEASUREMENT OF WATER BODIES IN TRINITY STUDY SITE AND GALVESTON STUDY SITE IN AUGUST 1972

Water Body	Area (hectares)		% Error	Absolute Error (Hectares)
	Aircraft	ERTS-1		
3	246.	246.8	0.3	0.8
4	61.1	58.1	4.9	3.
5	63.2	60.3	4.6	2.9
6	34.1	35.8	5.	1.7
7	28.3	31.4	11.	3.1
8	20.3	23.7	13.9	2.9
9	11.1	10.0	9.9	1.1
10	13.2	15.5	17.4	2.3
11	5.9	7.4	25.4	1.5
12	6.4	5.9	7.8	0.5
13	1.1	1.3	18.2	0.2
14	2.	3.4	70.0	1.4
15	8.5	8.9	4.7	0.4
C	10.1	8.9	11.9	1.2
D	37.4	31.8	15.0	5.6
E	20.8	15.6	25.0	5.2
F/G	1.7	1.3	23.5	0.4
H	29.	30.1	3.8	1.1
M/N	8.5	12.	41.2	3.5
			Average	2.0

were separate and continuous families of spectral reflectance signatures or curves for each feature type. Bright urban and sand signatures were intermixed. All Level III features investigated, such as water turbidity zones, algal mats, salt marsh, pine, and hardwoods were found to have unique and repeatable reflectance signatures (not grayscale signatures) for the three sets of ERTS-1 data considered (i.e., August 29, October 3, and November 26, 1972, data sets). These findings suggest that the use of a signature data bank should be explored to classify ERTS-1 data without the use of training fields if the atmosphere can be characterized by remote sensing as well.

The results of the evaluation suggest three potential applications of the ERTS-1 data to coastal survey problems as follows:

1. The detection of surface water bodies and the determination of their areal extents can be made from ERTS-1 data.

2. ERTS-1 data could be used to map coastal wetland areas of the State of Texas and other states to aid the states in the management of their state-managed wetlands, and to track trends in the reduction of wetland areas.

3. Turbidity patterns determined by the ERTS-1 data could be used in the verification and development of bay and estuarine circulation models now being developed by the U.S. Corps of Engineers and others.

2.0 INTRODUCTION

2.1 GENERAL OBJECTIVE

The general objective of the coastal investigation was to evaluate the performance of the ERTS-1 data acquisition system and its associated data processing system in obtaining and displaying information about the identity, location, and areal extent of coastal features of applications interest. This was part of the overall evaluation of the applications performance of the ERTS-1 sensor system performed at the NASA Johnson Space Center (JSC).

2.2 SPECIFIC OBJECTIVES

The specific objectives of this investigation were concerned with determining the performance of the ERTS-1 system in obtaining the data capable of being used to map certain coastal features. (A discussion of the features selected for investigation is provided in section 3.0.) To produce maps of a feature, one must be able to detect, identify, and locate the feature and determine its areal extent. The specific objectives of the coastal investigation are given below.

Feature Detection and Location. - The first specific objective was to determine the accuracy to which processed ERTS-1 data can be used to locate the position of detectable study features.

Spectral Uniqueness and Temporal Analysis. - The second specific objective was to determine the spectral

uniqueness of detectable features in the ERTS-1 spectral bands as a function of time. This objective was concerned with the identity of coastal features from the spectral and temporal properties of the feature as recorded by ERTS-1 systems.

Areal Measurement. - The third specific objective was to determine the accuracy to which processed ERTS-1 data can be used to measure the areal size of detected and identified features.

Classification Accuracy. - The fourth specific objective was to determine the classification accuracy of processed ERTS-1 data.

2.3 SCOPE

The ERTS-1 coastal investigation was limited to ERTS-1 multispectral-scanner (MSS) system-corrected tape and imagery data acquired over the Galveston Bay, Texas, complex from July 25, 1972, through February 24, 1973. The data were processed and analyzed to determine the information content of the ERTS-1 MSS data relative to the coastal features discussed in detail in section 3.0. The basis for the true identity, location, and areal extent of the study features was the conventional interpretation of high- and medium-level aircraft photography acquired during the study period. Field checks were used to aid in the interpretation. The data are presented and discussed in section 4.0 and related appendixes.

The ERTS-1 data selected for evaluation were processed by conventional and computer-aided means in a series of two

analysis cycles. The first, from December 1, 1972, to March 12, 1973, dealt with ERTS-1, aircraft, and field data acquired during the period of September 1, 1972, to December 1, 1972. The second, from March 12, 1973, to June 1, 1973, dealt with data acquired through February 23, 1973.

In the first cycle, conventional additive color and computer-aided clustering techniques were used. During the second cycle, conventional additive color and computer-aided clustering and maximum likelihood classification techniques were used. (Sections 7.0 and 8.0 provide detailed explanations of these analyses techniques.)

3.0 STUDY FEATURES

Coastal zone management requires the monitoring of a large number of coastal features. Due to the time and manpower constraints, the coastal analysis team decided to limit the coastal investigation to features associated with coastal water areas, coastal wetland areas, and barrier island areas. Furthermore, the features selected for investigation were arranged into an information hierarchy (figure 1-1) which attempted to consider both spectral separability and usability in management and science. This hierarchy is not intended to be complete; rather, it defines the coastal features that were studied during the investigation.

3.1 LEVEL I FEATURES

The Level I features are as follows:

a. Water
b. Wetland
c. Land

The water category included areas that were totally covered with water so that no vegetation or land substances protruded or lay on the surface of the water, except under extremely low tide conditions.

The wetland category referred to areas that were covered with shallow or intermittent waters so that the development of the vegetation was significantly affected by the intermittent presence of the water. These areas included

marshes, swamps, bogs, wet meadows, swales, potholes, sloughs, and river overflow lands (ref. 1).

The land category included areas in which vegetation was not significantly affected by water intrusion. Also included in the land category were nonvegetated areas that were not affected by tidal water action.

The classification of areas into the three Level I categories requires a precise knowledge of the frequency and extent of the intrusion and retreating of water in the area. Such data are not generally available. However, in many cases the boundaries among the three Level I categories can be established by determining the vegetal assemblages in the area, since some specific species of vegetation are quite sensitive to the duration and frequency of water intrusion and are sensitive to salinity and other chemical and physical properties of the water.

3.2 WATER SUBCATEGORIES

The Level II water features were spectrally different water masses. Water areas were expected to exhibit a wide range of reflectance values as a function of their physical and biological states. The mapping of spectrally different water masses is useful, even if the causative factors cannot be precisely defined. The further breakdown of information into the physical and biological states of a water mass was placed at Level III in the hierarchy. Also, circulation patterns that might be inferred from the spatial distribution of the spectrally different water masses were placed at Level III. Turbidity and chlorophyll content were

selected to be two of the most relevant physical and biological properties of water at Level III.

3.3 WETLAND SUBCATEGORIES

The three Level II features in the wetland category are

a. Swamp
b. Marsh
c. Nonvegetated wetland

The feature "swamp" is an area of wooded or shrub wetlands that is flooded occasionally by the overbanking of nearby fluvial systems and is slow to drain. Swamps in east and northeastern Texas contain several types of bottomland trees such as willow (*Salix* spp.), cypress (*Taxodium* spp.), mulberry (*Morus* spp.), water oak (*Quercus nigra*), gum (*Nyssa* spp.), and alder (*Alnum* spp.).

The feature "marsh" is an area of the wetlands that contains several types of marsh grasses. (The detailed description of these marsh grass types is given in the Level III discussion below.) Under the Level II marsh category, the three Level III features chosen were

a. Fresh marsh
b. Brackish marsh
c. Salt marsh

The feature "fresh marsh" contains vegetation that thrives in fresh water, such as bulrushes (*Scirpus* spp.), cattails (*Typha* spp.), arrowheads (*Sagittaria* spp.), alligator weed (*Alternanthera philoxeroides*), and roseau cane (*Phragmites communis*).

The feature "brackish marsh" is an area that contains vegetation such as big cordgrass (*Spartina cynosuroides*), gulf cordgrass (*Spartina spartinae*), bulrushes (*Scirpus* spp.), saltgrass (*Distichlis* spp.), and saltmarsh cordgrass (*Spartina alterniflora*). The water in a brackish marsh has a medium salinity range.

The feature "salt marsh" is an area of the wetland that contains salt-tolerant vegetation such as saltmarsh cordgrass (*Spartina alterniflora*), salt meadow cordgrass (*Spartina patens*), needlerush (*Juncus roemerianus*), and glasswort (*Salicornia* spp.).

The survey of the above types of wetlands on a regular basis is important for several reasons. First, wetland marshes serve as habitats for many important types of wildlife, such as fur-bearing animals, waterfowl, and game animals. Optimum flyway management requires an accurate assessment of the location and types of wetlands in the flyways of migrating fowl. Second, wetlands are useful for water control planning both for flood control and for water quality. Third, marsh vegetation is an important source of nutrients for rangeland animals as well as for marine and marsh wildlife. The production of organic material by healthy marsh vegetation is the highest of all natural vegetation types in the world on an annual and per unit area basis. Fourth, wetlands may be filled or dredged for land fill, urbanization, and transportation. Fifth, the State of Texas owns all land seaward of the mean high tide and would like to have this wetland property adequately mapped.

Wetlands are now under the jurisdiction of local, regional, state, and federal government agencies. Hundreds of hectares of wetlands are being filled and changed from their present use every year. Wetland inventories are needed as a basis for making decisions for the intended use of specific wetland areas.

3.4 LAND SUBCATEGORIES

The three Level II features in the land category are

a. Sand
b. Barrier flat vegetation
c. Other (urban, forest, crop, grassland)

The feature "sand" included the areas covered predominantly by dry sand.

The feature "barrier flat vegetation" included salt-tolerant vegetation found on the barrier island flat area between the beach and the back island marshes. The vegetation included grasses such as salt meadow cordgrass (*Spartina patens*), gulf cordgrass (*Spartina spartinae*), and other vegetation such as bluestem, rattlebox, elderberry, and a variety of shrubs and weeds.

The survey of sand, barrier flat vegetation, and salt marsh vegetation on a barrier island was needed to determine the condition of the island. In some cases, resource managers need to decide on a course of restoration for the island, such as pumping sand to the beaches or fertilizing barrier flat vegetation.

4.0 STUDY AREA

The study area for the ERTS-1 coastal investigation was selected in a zone of overlapping coverage between two consecutive ERTS-1 overpasses. This zone is outlined by the large black partial rectangle in figure 4-1 and includes portions of the Galveston Bay complex and surrounding land masses in the Texas coastal zone.

The region of overlap was approximately 50 kilometers (30 n. mi.) wide. Depending upon the framing of the ERTS-1 data and the drift in orbit, the study area may be contained within one or more ERTS-1 frames and/or ERTS-1 computer-compatible tapes.

The Galveston Bay complex represents an interactive ecological region that has been heavily influenced by human activity. Two barrier island systems, Galveston Island and Bolivar Peninsula, separate the Bay from the Gulf of Mexico. Ship channels traverse the area (Intracoastal Waterway, Houston Ship Channel, Texas City Ship Channel, Trinity Ship Channel, and others). Also, the oceanside beach is a recreation area for thousands of people. This beach has been eroding over the last several decades due to the damming of Texas river systems and the change in the Mississippi River waterway to a more easterly position several hundred years ago.

Two major urban and industrial areas are located within the study area, Galveston, Texas, and Texas City/LaMarque,

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-545-S

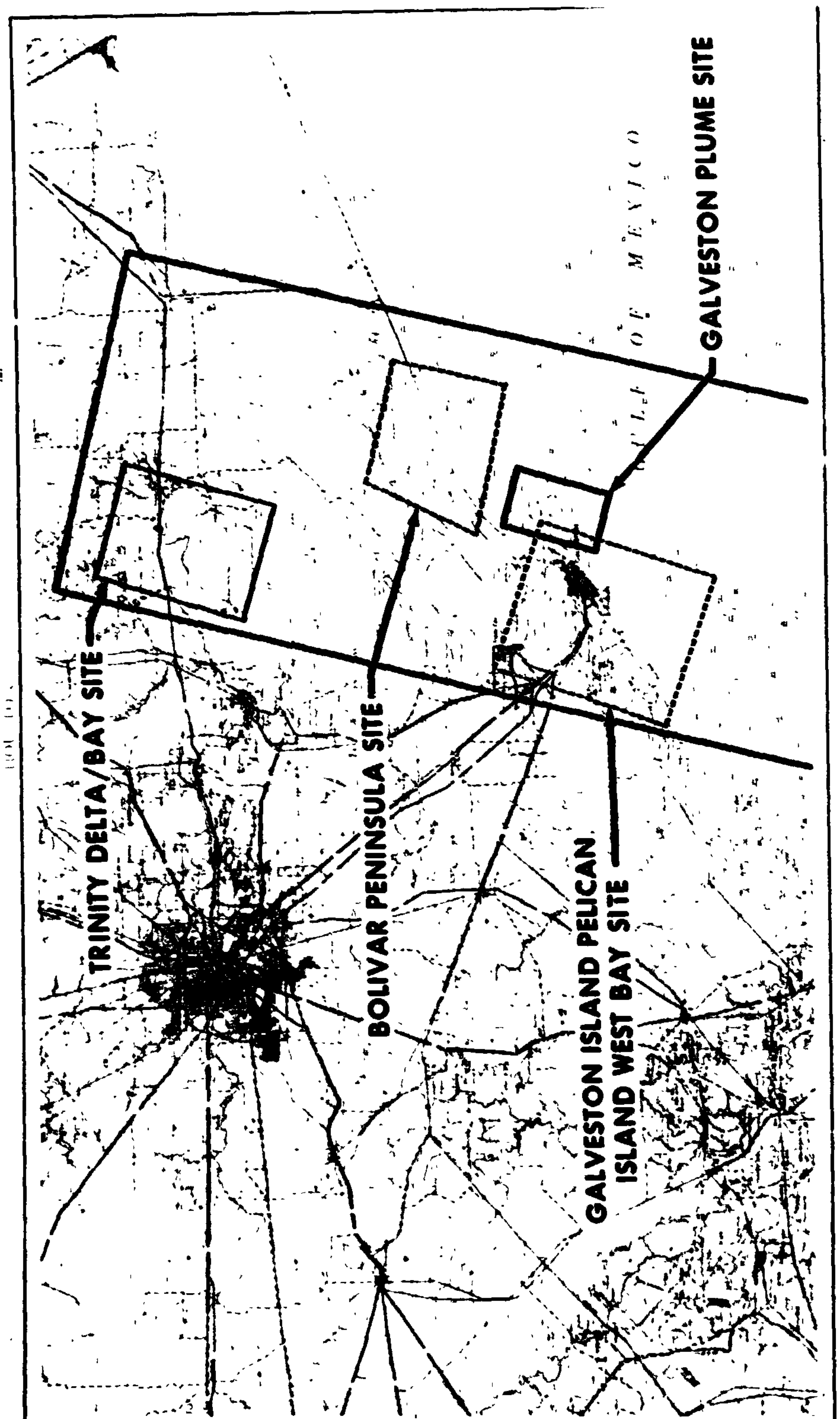


Figure 4-1.- Coastal study area.

Texas. These urban areas are growing, and the wetland, mainland, and island areas are being converted to urban use.

The major sources of fresh water into the Galveston Bay complex are the Trinity and San Jacinto Rivers at the north end of the bay system. Shrimping and shell fishing are major industries in the area. Algae blooms are common, and industrial water pollution is a recognized problem. Wetlands are used for c ttle feeding and to support wildlife, especially wildfowl. Adjacent land areas are used for rice farming. An extensive system of water canals is present in the surrounding farming areas. Sport fishing and other water recreation are popular pastimes in the Galveston Bay complex.

Within the study area, four smaller study sites were chosen for thorough investigation:

a. Trinity Study Site
b. Galveston Study Site
c. Bolivar Study Site
d. Galveston Plume Study Site

4.1 TRINITY STUDY SITE

The Trinity study site is an area that contains the lower portion of the wetlands associated with the Trinity River and upper Trinity Bay. The site is outlined by a solid green line in figure 4-1. The Trinity delta is a wetland region that has been changing slowly from fresh marsh to salt marsh due to subsidence and damming of Trinity River water. Lake Anahuac is the largest contiguous fresh water body in the area.

The major manmade influences in the area are the Wallisville Reservoir that is under construction and the Houston Lighting and Power Company's cooling pond. This pond is not shown in figure 4-1, since it had not been planned at the time of map preparation. Interstate Highway 10 runs east and west across the study area.

Mixed pine and deciduous forest areas occupy the northern part of the site, and rice farming is common in the areas surrounding the river delta. Because of the nature of rice farming, bare soil, flooded fields, or rice may be observed at different times during the year.

4.2 GALVESTON STUDY SITE

The Galveston study site is outlined in red in figure 4-1. The major features of interest to the coastal analysis team in this study area were the salt marshes, the edges of West Bay, the beach sand along the oceanside of Galveston Island, and the barrier flat vegetation. Extensive efforts by man to stabilize Galveston Island have caused unnatural sedimentary evolution. As a consequence, the beach areas are rapidly eroding, and bayside marsh areas are narrow (ref. 2).

West Bay is shallow and is somewhat separated from the rest of the Galveston Bay complex by the Texas City dike. Texas City is heavily industrialized, consisting primarily of petrochemical plants. Recreational housing areas are being built on the west end of Galveston Island.

4.3 BOLIVAR STUDY SITE

The Bolivar study site is outlined in dark blue in figure 4-1. Bolivar Peninsula is essentially a barrier island, since it is connected to the mainland only by a narrow neck of land on the east end.

Two large salt marsh areas occur on the landward side of Bolivar Peninsula. The area is relatively uninfluenced by human activities, since it is accessible only by boat, or by a seldom-traveled road to the east. The beaches at the southwest end of Bolivar are building up due to the existence of jetties at the west end of the peninsula. The Intracoastal Waterway runs through the length of the area.

4.4 GALVESTON PLUME STUDY SITE

The last study site selected was the Galveston Plume study site shown as the small black rectangle in figure 4-1. The site was selected for the concentrated study of the change in water properties across a short distance.

4.5 PREVIOUS CHARACTERIZATIONS OF THE STUDY AREA

Several maps of coastal features were made of the coastal study area and surrounding areas by the Bureau of Economic Geology, The University of Texas at Austin, Texas (ref. 3). Three of these maps are displayed in figures 4-2, 4-3, and 4-4. Figure 4-2 is a topographic and bathymetric map, figure 4-3 is an environmental and biologic assemblages map, and figure 4-4 is a land-use map of the area. The maps are self-explanatory and are included to provide the

reader with a synoptic view of the naturally occurring variations and diversity in the geography of the study area. These maps were used in the coastal investigation to aid in the familiarization of the study sites, in the interpretation of the high-altitude aircraft photography, and in the selection of field check points.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

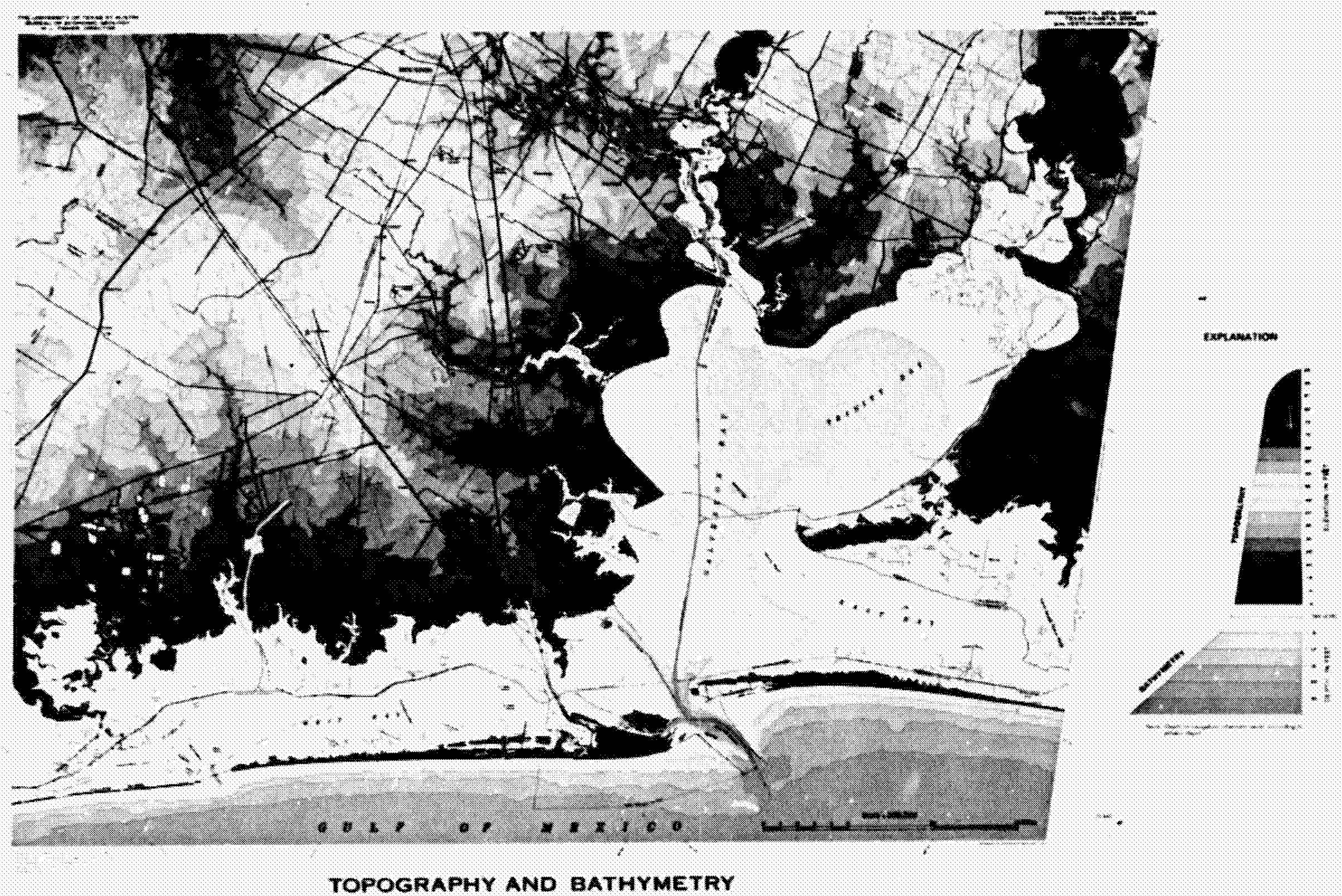


Figure 4-2.— Topographic and bathymetric map of study area (ref. 3).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

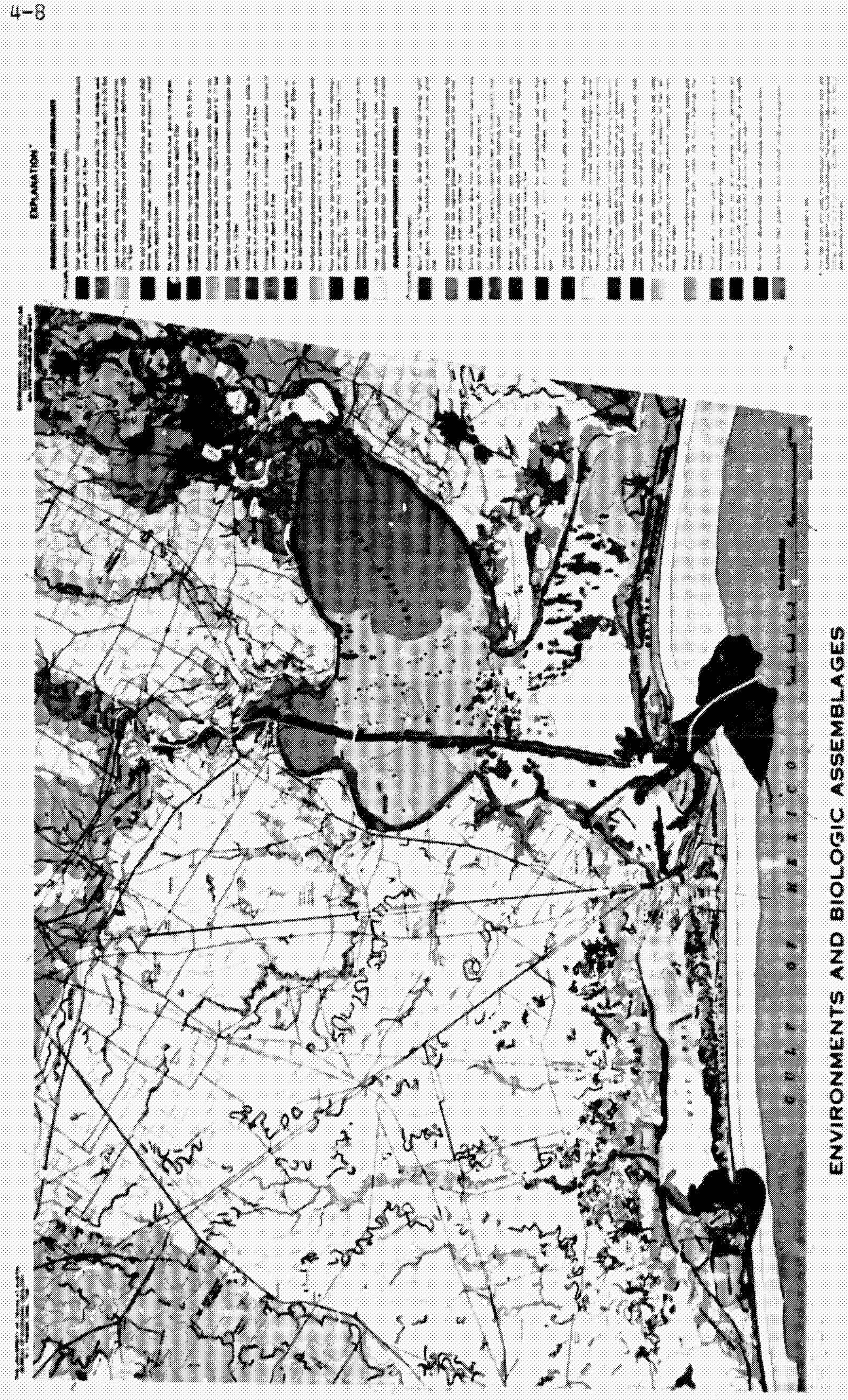


Figure 4-3.- Biological assemblages map of study area (ref. 3).

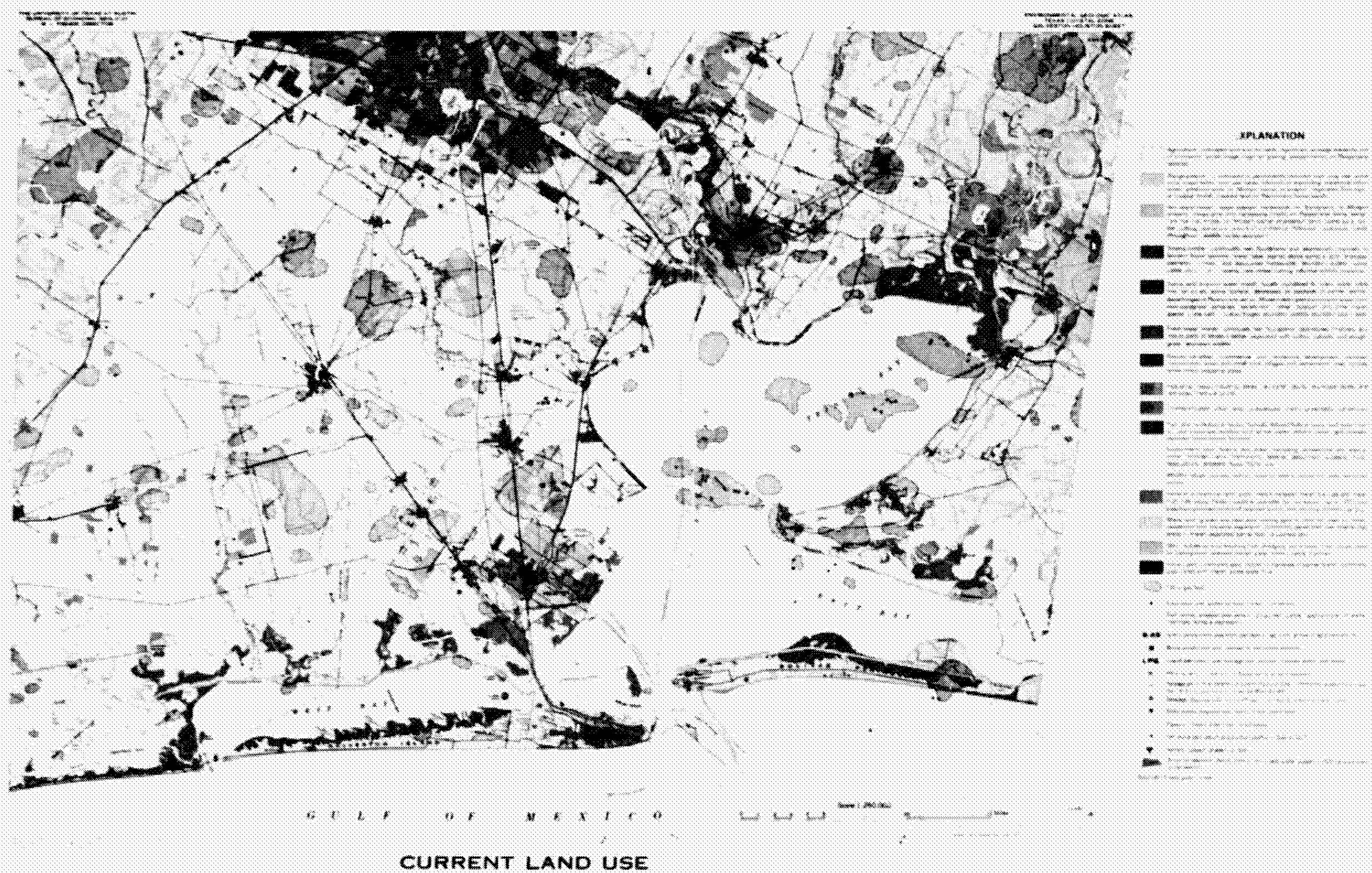


Figure 4-4.— Land-use map of study area (ref. 3).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

5.0 AIRCRAFT AND FIELD SURVEY INFORMATION

The main source of information upon which the true identity, location, and areal extent of the coastal study features were based was aircraft photography of the study sites at or near the times of the ERTS-1 coverage. In addition, some field checks were made in the study sites during the first half of 1973. These checks were made for three purposes: (1) to aid in the determination of wetland and land feature boundaries through the use of the aircraft photography, (2) to support ERTS-1 data acquired during the first half of 1973 over the coastal study sites so that these data could be evaluated in the post ERTS-1 sensor applications performance evaluation period, and (3) to determine the relationship between water reflectance in the ERTS-1 spectral bands and the properties of the water (turbidity and chlorophyll, as well as other chemical and physical properties).

The aircraft data are presented in this section to aid the reader in interpreting the ERTS-1 performance. Also, frequent references are made to these data in the remainder of the report because they serve as the primary basis for the definition of training, identification, and test areas for the study features for each of the ERTS-1 data sets that was processed and evaluated. The majority of the field survey information is presented as supplementary material in appendix A.

5.1 AIRCRAFT SURVEY INFORMATION

Table 5-I lists the occurrences of the aircraft support flights.

TABLE 5-I.- SUMMARY OF AIRCRAFT SUPPORT MISSION
(JULY 1972 TO JULY 1973)

Mission Number	Mission Date	Average Mission Time (G.m.t.)	Sites Covered	Nearest Clear-Sky ERTS-1 Pass	
				Date	Time (G.m.t.)
208	Aug. 30, 1972	16:30	All	Aug. 29, 1972	16:24
216	Oct. 3, 1972	15:46	Trinity	Oct. 3, 1972	16:19
220	Nov 7, 1972	20:26	All	Nov. 26, 1972	16:20
228	Jan. 19, 1973	16:13	All	Jan. 19, 1973	16:20

5.1.1 Mission 208

Mission 208 was flown August 30, 1972, between 16:20 and 16:40 G.m.t. at an approximate altitude of 18.6 kilometers (61 000 ft) above all the coastal study sites. The primary sensor onboard the WB-57 aircraft was an RC-8 metric camera with color infrared film (2443).

Three frames that covered the three coastal study sites were selected for enlargement and rectification (figures 5-1, 5-2, and 5-3).

These photographs were used to locate the study features of each site. As a result, three thematic maps were prepared (figures 5-4, 5-5, and 5-6). These maps displayed a photointerpretation of the location of Level I water,

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28194

Figure 5-1.- Rectified aircraft photograph of Trinity Study Site (2443 film collected August 30, 1972, mission 208).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-25516

Figure 5-2.- Rectified aircraft photograph of Galveston Study Site (2443 film, August 30, 1972, mission 208).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-25515

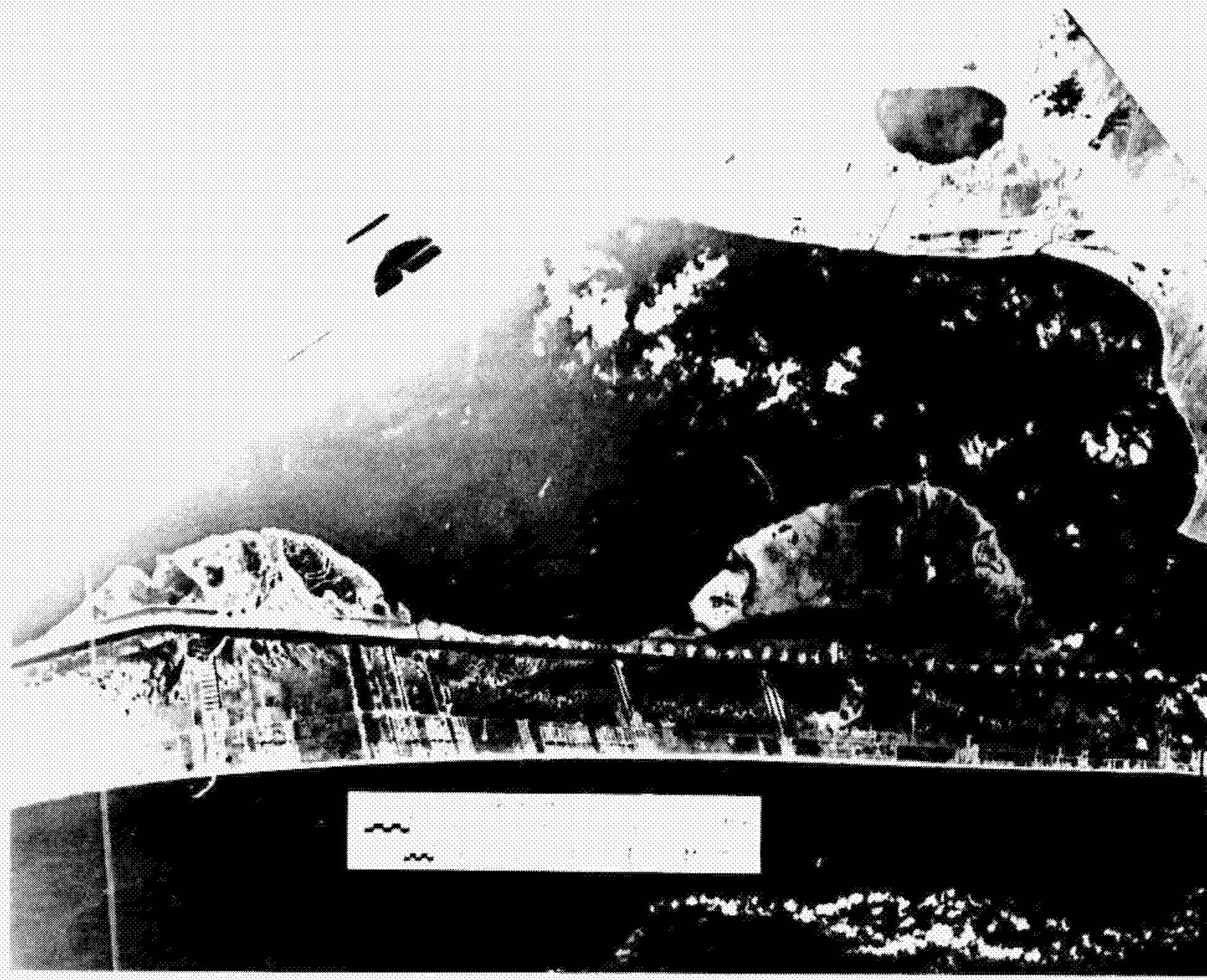


Figure 5-3.- Aircraft photograph of Bolivar Study Site (2443 film collected August 30, 1972, mission 208).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28193

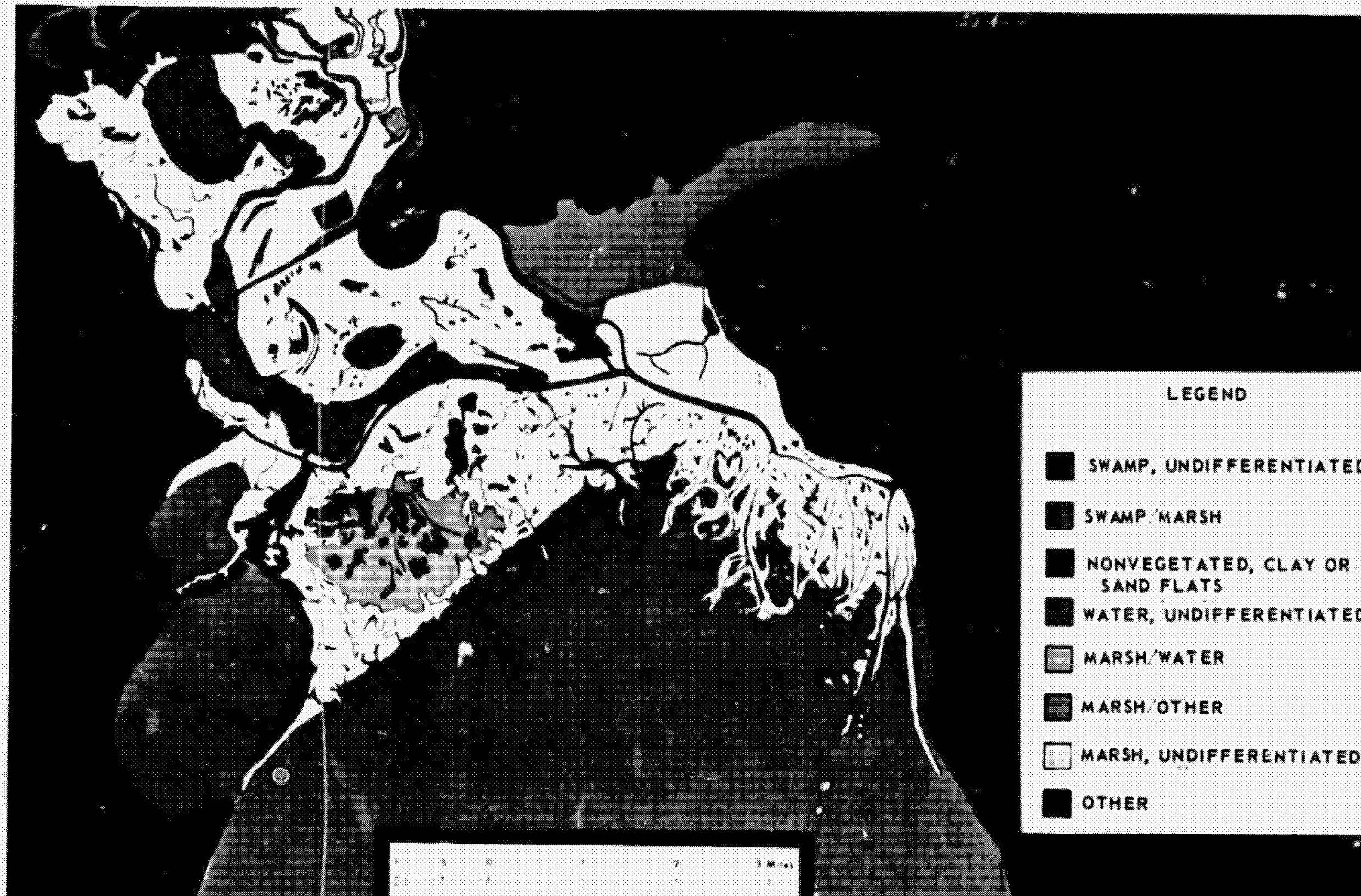


Figure 5-4.– Thematic map of coastal study features, Trinity Study Site (based on aircraft data).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-1127

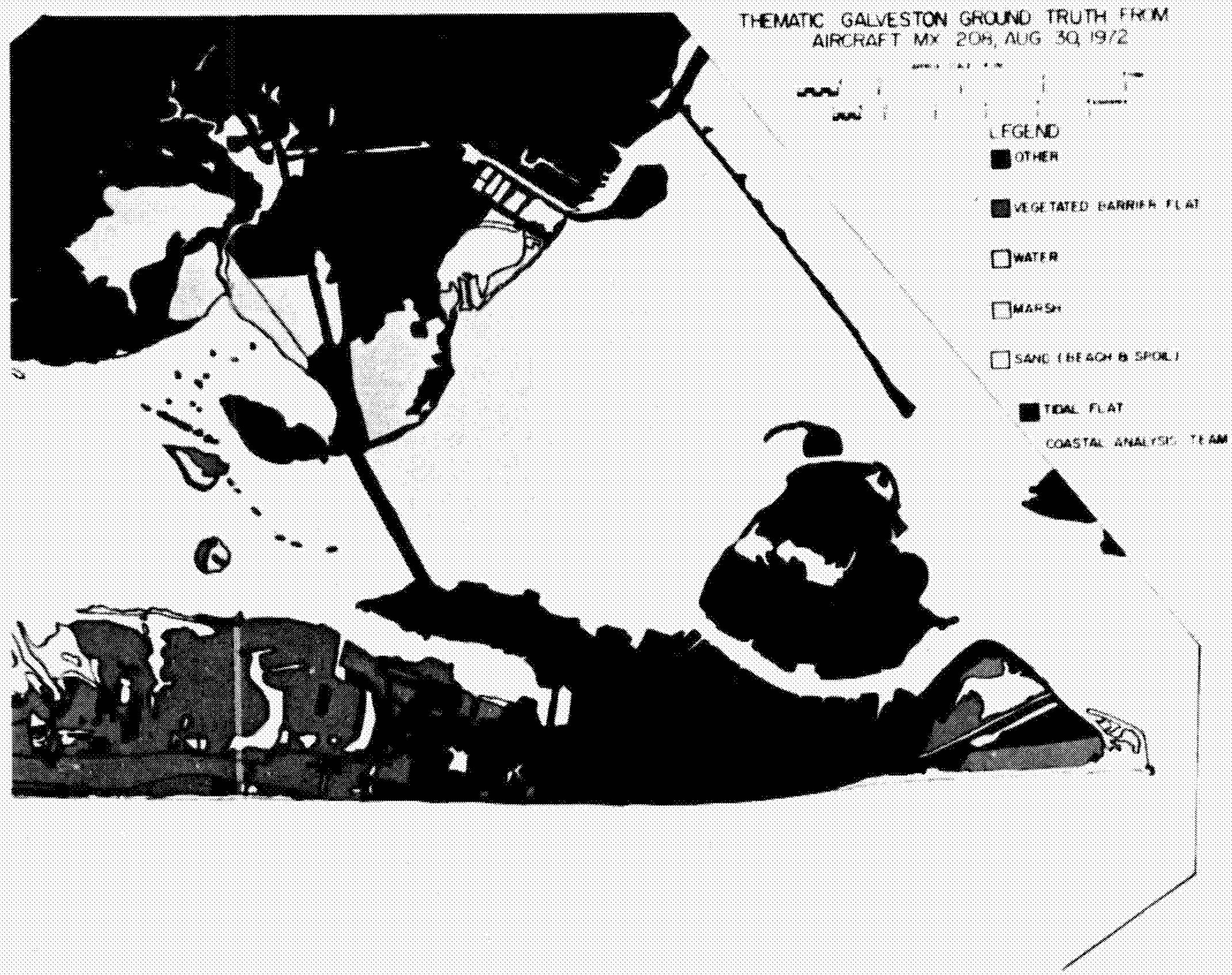


Figure 5-5.- Thematic map of coastal study features, Galveston Study Site (based on aircraft data).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-1126

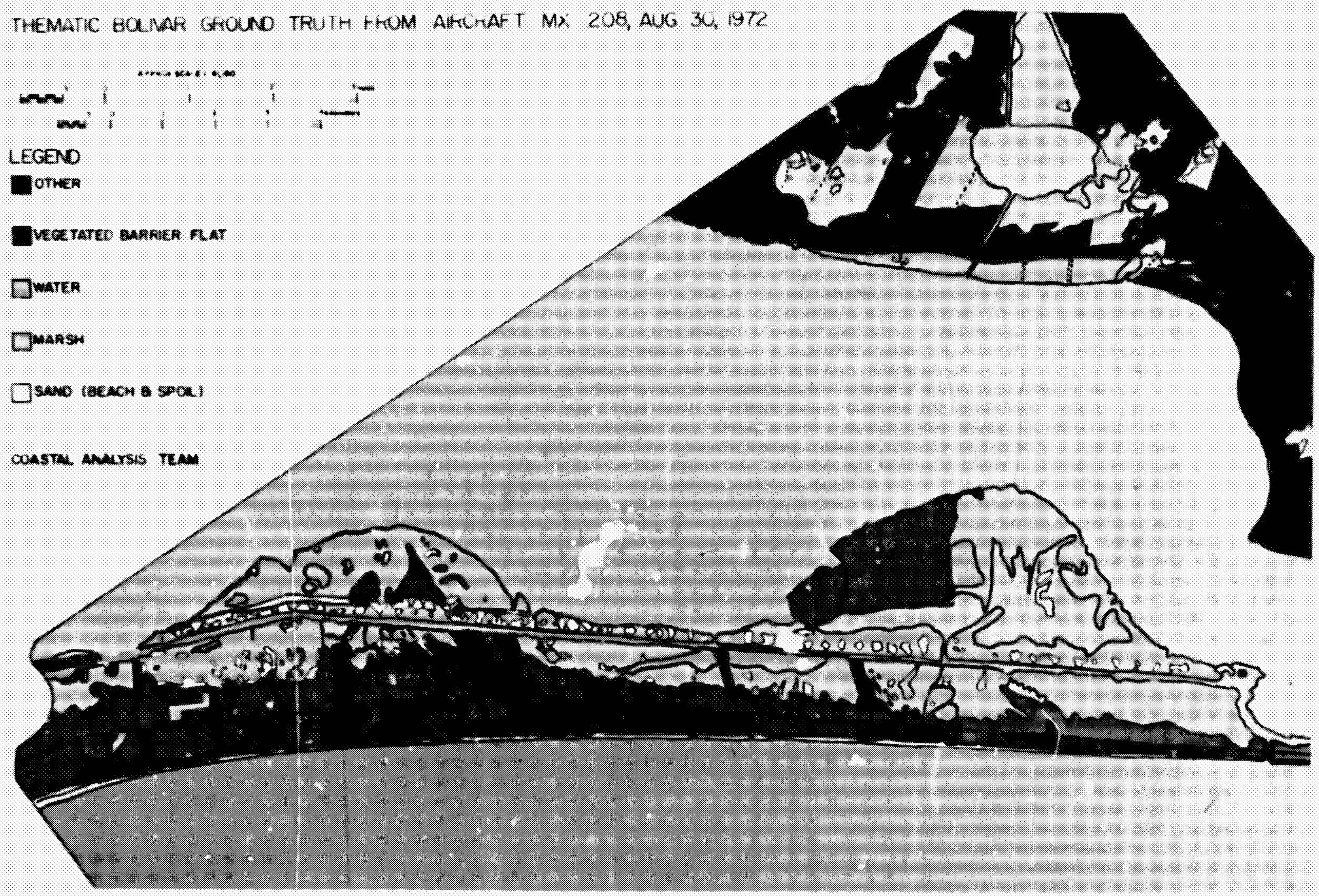


Figure 5-6. - Thematic map of coastal study features, Bolivar Study Site (based on aircraft data).

Level II wetland, and Level II land features as evident from the aircraft photography. Previous historical data taken over each study site in the coastal study area and field checks made in the first half of 1973 were used to aid in these interpretations.

These interpretations and photographs were used to aid in the evaluation of ERTS-1 data acquired over the study sites on August 28 and 29, 1972.

Areal extent of water bodies. – Accurate measurements of these areas were required from aircraft photography to determine the accuracy of ERTS-1 data being used to measure the surface extent of water bodies. The aircraft data analyzed for this purpose were taken on August 30, 1972, during mission 208 in support of the ERTS-1 overpasses on August 28 and 29, 1972.

The only coastal study sites that contain contiguous water bodies are Trinity and Galveston Study Sites. A number of water bodies were located in each site photograph (figures 5-1 and 5-2) and their areal extents were determined through the use of a planimeter (photographic data quantizer). The results of these measurements are given in section 9.0, and they are used in comparison to areas of the same water bodies determined from ERTS-1 data taken on August 29, 1972, over the same study sites.

Areal extent of salt marsh areas. – Aircraft photography was taken August 30, 1972, by the NASA WB-57 over the Galveston Study Site. The frame containing the study site (figure 5-2) was rectified and enlarged to a scale of 1:41,150.

The wetlands were delineated and measured using a photographic data quantizer, and these measurements were compared with the areas obtained from ERTS-1 data. These data are given in section 9.0.

5.1.2 Mission 216

Mission 216 was flown October 3, 1972, at 15:46 G.m.t. over the Trinity Study Site at an approximate altitude of 3 kilometers (10 000 ft) above the study site. Color Ektachrome (film SO 397, haze filter) photography was taken by the NASA NC-130 aircraft RC-8 camera system. Four bands of photography also were obtained using panchromatic film 2424 and four filters (blue pass, filter 47B; green pass, filter 57; red pass, filter 25; and near-infrared pass, filter 89B) in a set of four Hasselblad 70-mm cameras. All the data were collected within 33 minutes of the ERTS-1 pass over the Trinity Study Site on October 3, 1972. The coverage of the data is shown by the mosaic of the Ektachrome photography (SO 397, haze filter) shown in figure 5-7. This mosaic was used to aid in the interpretation of ERTS-1 data acquired over the Trinity Study Site on October 3, 1972.

5.1.3 Mission 220

Mission 220 was flown November 7, 1972, between 20:18 and 20:34 G.m.t. at an approximate altitude of 18.6 kilometers (60 000 ft) above the study sites. The sensors were the same as those flown on Mission 208. The flight was in support of ERTS-1 overpasses on November 8 and 9, 1972. The sky was cloudy on these ERTS-1 passes; the nearest clear weather ERTS-1 pass was November 26, 1972. Three frames were selected as a basis for the ERTS-1 evaluation.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA-S-73-28192

TRINITY DELTA/TRINITY BAY

ERTS-1 PROJECT COASTAL ANALYSIS TEAM

APPROXIMATE SCALE

Figure 5-7.– Uncontrolled mosaic of Trinity Study Site (mission 216 RC-8 photography gathered October 3, 1972, film SO 397).

These are shown in figures 5-8, 5-9, and 5-10. The task of rectifying and enlarging these photographs had not been completed as of July 1, 1973; therefore, the aircraft data could not be used to establish the areas of the study features in November 1972. The aircraft photography was used, however, for feature location and identification to support the November 26, 1972, ERTS-1 data acquisition over all coastal study sites.

5.1.4 Mission 228

Mission 228 was flown January 19, 1973, between 16:05 and 16:21 G.m.t. at an approximate altitude of 18.6 kilometers (60 000 ft) above the study sites. The flight was flown concurrently with the ERTS-1 coverage on the same day. A boat survey also was conducted in the area where Galveston Bay flows into the Gulf of Mexico.

Two Zeiss photographs obtained during mission 228 are shown in figures 5-11 and 5-12. The first photograph is of a portion of the Trinity Study Site. The second photograph shows a portion of the Galveston Study Site. These photographs were used to support the evaluation of the ERTS-1 data acquired on January 19, 1973, as well as the previous ERTS-1 acquisitions.

5.2 FIELD SURVEY INFORMATION

In support of the aircraft surveys and ERTS-1 data acquisitions, a number of field checks were made in the study sites to determine coastal feature boundaries and to relate water reflectance to water properties. Field data were acquired by members of the coastal analysis team.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28103

Figure 5-8.- Trinity Study Site aircraft photography collected November 7, 1972 (mission 220, RC-8 frame 10, film 2443).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28101

Figure 5-9.- Galveston Study Site aircraft photography collected November 7, 1972 (mission 220, RC-8 frame 5, film 2443).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28102

Figure 5-10.- Bolivar Study Site aircraft photography collected November 7, 1972 (mission 220, RC-8 frame 15, film 2443).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28100

Figure 5-11.- Trinity Study site aircraft photography collected January 19, 1973 (mission 228, Zeiss frame 7, film 2443).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28106

Figure 5-12 - Galveston Study Site aircraft photography collected January 19, 1973 (mission 228, Zeiss frame 18, film 2443).

Automobiles, boats, and a helicopter were used to gain access to the sites. A major problem in the collection of field data was the lack of access to fenced private property in the wetland area. This lessened the ability to map Level III features. In addition to field surveys fulfilling a primary support role, they provided a basis for understanding the relationship between the radiation reflected from study features and their physical and biological properties.

The extensive field data are given in detail in appendix A. Relevant conclusions from the field work are given below.

1. Boundaries do not appear as distinct lines as suggested by maps. Rather, boundaries normally occur in nature as ecological gradients between environments.
2. Peak water reflectance shifts from the blue through green to red band (λ 600 to 700 nm) as water turbidity increases.
3. The correlation between water reflectance in the ERTS-1 bands and surface water turbidity (FTV or ppm) is high. (The correlation coefficients for ERTS-1 MSS bands 4 and 5 are 0.88 and 0.915.)
4. The water was a non-Lambertian surface, so that the absolute reflected intensity of radiation from the water's surface at the nadir viewing angle did not vary appreciably with changes in the incident solar zenith angle for water having similar turbidities.

6.0 ERTS-1 DATA

This section describes the characteristics of the ERTS-1 sensor systems and platform so that the nature of the sensor applications performance of ERTS-1 can be understood.

The ERTS-1 was launched on July 23, 1972, and was placed into a polar sun-synchronous orbit approximately 903 kilometers above the earth's surface. Its inclination is 14° from north (014° to 194°). The ERTS-1 repeats its general orbital pattern every 18 days. It passes the coastal study area at about 16:19 to 16:26 G.m.t. (10:19 to 10:26 l.s.t.).

The primary sensors on the ERTS-1 are the multispectral scanner (MSS) and the return beam vidicon (RBV). The RBV was turned off after the first few days of ERTS-1 operation because of a tape recorder problem. The ERTS-1 data are telemetered to the ground station in digital form, calibrated, recorded on various film formats, and recorded on duplicate computer-compatible tapes (CCT). These data were received at JSC about 60 to 90 days after the acquisition date.

6.1 ERTS-1 MULTISPECTRAL SCANNER SYSTEM

The ERTS-1 multispectral scanner (MSS) system is a line-scan device that maps the emergent radiation from the earth's surface and atmosphere over four bands as shown in table 6-I.

TABLE 6-I.- MSS BANDS

Band	Wavelength	Bandpass*
MSS4	500 to 500	nm
MSS5	605 to 700	nm
MSS6	693 to 800	nm
MSS7	810 to 990	nm

*Half-power limits.

Differences in relative spectral response and calibration parameters among the six detectors of any given MSS band cause striping effects in the ERTS-1 MSS images.

The motion of the spacecraft permits the ERTS-1 MSS data to be acquired line by line so that a continuous image is obtained. The data are framed so that each frame contains MSS data over a 185-kilometer (100 by 100 n. mi.) square. The frame is 3240 picture elements wide (east-west) and 2480 scan lines long (north-south). The digital computer-compatible tapes (CCT) that contain ERTS-1 MSS data are 810 elements wide and 2480 lines long, which is one-quarter of an ERTS-1 frame. Each CCT contains about two million picture elements.

The remote sensing data for each picture element consist of four sets of binary numbers ranging over the arbitrary scales shown in table 6-II. The relationships in table 6-II are valid for the decompressed, linear, low-gain mode of operation that has been used for all of the data contained in this report.

TABLE 6-II.- RANGE OF ERTS-1 MSS DATA

Band	Grayscale Range	Mean Specific Intensity* ($mw\ cm^{-2}\ sr^{-1}\mu^{-1}$)	
		Low End	High End
MSS4	0-127	0	24.8
MSS5	0-127	0	21.1
MSS6	0-127	0	16.4
MSS7	0-63	0	25.6

* Equal to intensity averaged over bandpass function.

The film record of MSS data is processed originally as a positive transparency (70-mm format) at the NASA Goddard Space Flight Center. The copies of these data that are supplied to JSC are third-generation positive transparencies and prints in either 70-mm or 240-mm (9.5-in.) format.

6.2 SUMMARY OF ERTS-1 DATA ACQUIRED OVER THE COASTAL STUDY AREA

For the period of July 23, 1972 through July 1, 1973, there were 38 ERTS-1 overpasses over the coastal study area. The weather was satisfactory on 11 of these passes (i.e. 29 percent). Table 6-III gives a complete summary of the passes, their related weather condition, and aircraft and field support.

TABLE 6-III.- SUMMARY OF ERTS-1 PASSES OVER THE COASTAL STUDY AREA

Date	ERTS-1 Day	Cloud Cover	Nearest Aircraft Coverage	Field Support	Status of Analysis
8/10&11/72	1018-9	100	8/30/72	none	NA
8/28&29/72	1036-7	10	3/30/72	haze*	Complete
9/15/&16/72	10-54-5	100	8/30/72	none	NA
10/3/72	1072	0	10/3/72	haze	Complete
10/4/72	1073	20	10/3/72	haze	NA
10/21&22/72	1090-1	60	11/7/72	none	NA
11/8&7/72	1108-9	100	11/7/72	none	NA
11/26/72	1126	0	11/7/72	none	Complete
11/27/72	1127	60	11/7/72	haze	NA
12/14&15/72	1144-5	100	1/19/73	none	NA
1/1&2/73	1162-3	100	1/19/73	none	NA
1/19/73	1180	0	1/19/73	Boat,haze, Trinity**	Partially Complete
1/20/73	1181	100	1/19/73	none	NA
2/6&7/73	1198-9	100	1/19/73	none	NA
2/24/73	1216	20	1/19/73	none	Partially Complete
2/25/73	1217	100	1/19/73	none	NA
3/14&15/73	1234-5	100	1/19/73	none	NA
4/1/73	1252	0	1/19/73	none	Incomplete
4/2/73	1253	100	1/19/73	Boat	NA
4/19&20/73	1270-1	100	1/19/73	none	NA
5/7/73	1288	100	1/19/73	none	NA
5/8/73	1289	0	1/19/73	Boat	Incomplete
5/25&25/73	1306-7	100	1/19/73	none	NA
6/12&13/73	1324-5	100	1/19/73	none	NA
6/30/73	1342	100	1/19/73	none	NA
7/1/73	1343	100	1/19/73	none	NA

*Aerosol optical depth measurements were made in some portions of the coastal study area (data needed for atmospheric correction).

**Field survey was made in the Trinity Study Site.

7.0 CONVENTIONAL PROCESSING

The basic input to conventional processing consisted of positive and/or negative transparencies of ERTS-1 data on either 70-mm or 240-mm (9.5-in.) format. The coastal investigation used only system-corrected imagery from the multispectral scanner (MSS) system. Furthermore, most of the conventional analysis was performed on the fifth-generation 240-mm (9.5-in.) positive transparencies. Fifth-generation transparencies were used because the third-generation transparencies produced by the NASA Goddard Space Flight Center were too dense for enhancement by color additive machines at NASA/JSC. The rest of the conventional analysis was performed on the first-generation negative transparencies produced from the digital multispectral scanner data magnetic tapes on the Data Analysis Station (DAS), section 8.0.

7.1 NONENHANCED IMAGERY

Two particular frames of ERTS-1 240- by 2[illegible]-mm imagery acquired over the coastal study area February [illegible], 1973, are shown in figures 7-1 and 7-2. Figure 7-1 is MSS band 4, and figure 7-2 is MSS band 6. Note the bright area in the western half of Galveston Bay in figure 7-2. This area is correspondingly dark in figure 7-1. The Texas Parks and Wildlife Service determined that the bright area was a non-toxic bloom of reddish brown algae (*Exvella balteca*) that spread from Seabrook, Texas, in late January to the imaged occurrence on February 24, 1973.

Figure 7-1. - Plankton bloom of MSS band 4 imagery acquired February 24, 1973.

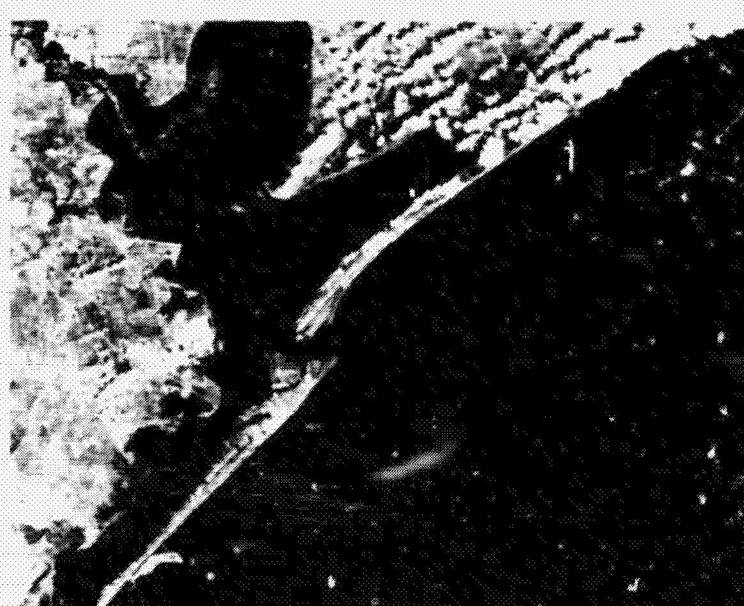


Figure 7-2. - Plankton bloom of MSS band 6 imagery acquired February 24, 1973.

7.2 CONVENTIONAL ENHANCEMENT PROCESSING

The basic technique that has been used in processing ERTS-1 film data was the density slicing or contrast enhancement operation performed on the film data through the use of the multiband camera film viewer (MCFV).

After the operator of the MCFV registered up to three bands of film data, he used the MCFV to divide a selected portion of the gray scale of a particular band of imagery into 15 equally spaced divisions. The operator then may display any given division as a combination of three primary colors (blue, green, and red). Thus, the operator may assign one of a large variety of colors to each of the 15 divisions of the density or grayscale values presented on the film data. Furthermore, the operator may register up to three bands of film data and combine the results of the density slicing of each band separately into an overall composite additive color picture. Also, logarithmic and exponential operations may be applied to the film data. The overall result of this type of film contrast enhancement is the production of different colors in the image that represent certain ranges of density in one, two, or three bands of imagery.

Certain limitations inherent in the instrument are imposed on the analysis of data, such as the capability to detect and enhance features of the imagery within the density ranges of 0.4 and 2.0. Much of the data received from the GSFC was high density and exceeded the upper limit (beyond the 2.0 density range). Some of the processing products presented are characteristic of analysis using data that were reproduced from third-generation copies to make fifth-generation working copies, and consequently,

was of degraded quality. This operation greatly improved the detectable information content of the data analyzed as fourth-generation negatives and fifth-generation positives.

Another approach to this problem was to produce first-generation black-and-white negatives from the data analysis station (DAS) film recorder. This process appeared relatively simple, but it required six runs to finally produce a suitable set of three black-and-white transparencies. Only the features of interest relative to the objectives of the coastal investigation were enhanced. Other details that were apparent in the imagery were combined on the DAS into broad categories such as land or were blanked out in thresholding.

Examples of the images produced through the conventional additive color processing on the MCFV are given in figures 7-3 through 7-13. Setups for the MCFV for these figures are given in table 7-I, as well as the site, acquisition date, and general level of information. Levels refer to the information hierarchy in figure 1-1. The results of the data analysis are given in section 9.0.

TABLE 7-I.- INFORMATION RELATED TO CONVLNTIONAL PROCESSING IMAGES PRODUCED BY MCFV

Figure Number	Study Site	Date of ERTS-1 Data Acquisition	Analog (A) or Digital (D)	Generation of Film Used	Approx. Level of Image	ERTS-1 Bands Used
7-3	Trinity	August 29, 1972	A	5	II	4, 5, and 7
7-4	Trinity	August 29, 1972	D	5	II	5 and 7
7-5	Trinity	January 19, 1973	D	4	II	4, 5, and 7
7-6	Galveston	August 29, 1972	A	5	II	4, 5, and 7
7-7	Galveston	August 29, 1972	D	5	II	4, 5, and 6
7-8	Galveston	August 29, 1972	D	5	III	4, 5, and 6
7-9	Galveston	November 26, 1972	D	4	II	5 and 6
7-10	Galveston	October 3, 1972	D	1	II	4, 5, and 6
8-11	Bolivar	August 28, 1972	D	1	III	7
8-12	Bolivar	November 26, 1972	D	4	II	5 and 6
8-13	Bolivar and Galveston	January 19, 1973	D	4	II	4, 5, and 7

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-25523

Figure 7-3.- Color composite of Trinity Study Site (imagery acquired August 29, 1972, MCFV, analog, MSS bands 4, 5, and 7, fifth-generation film). See last paragraph of page 7-4.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-25477

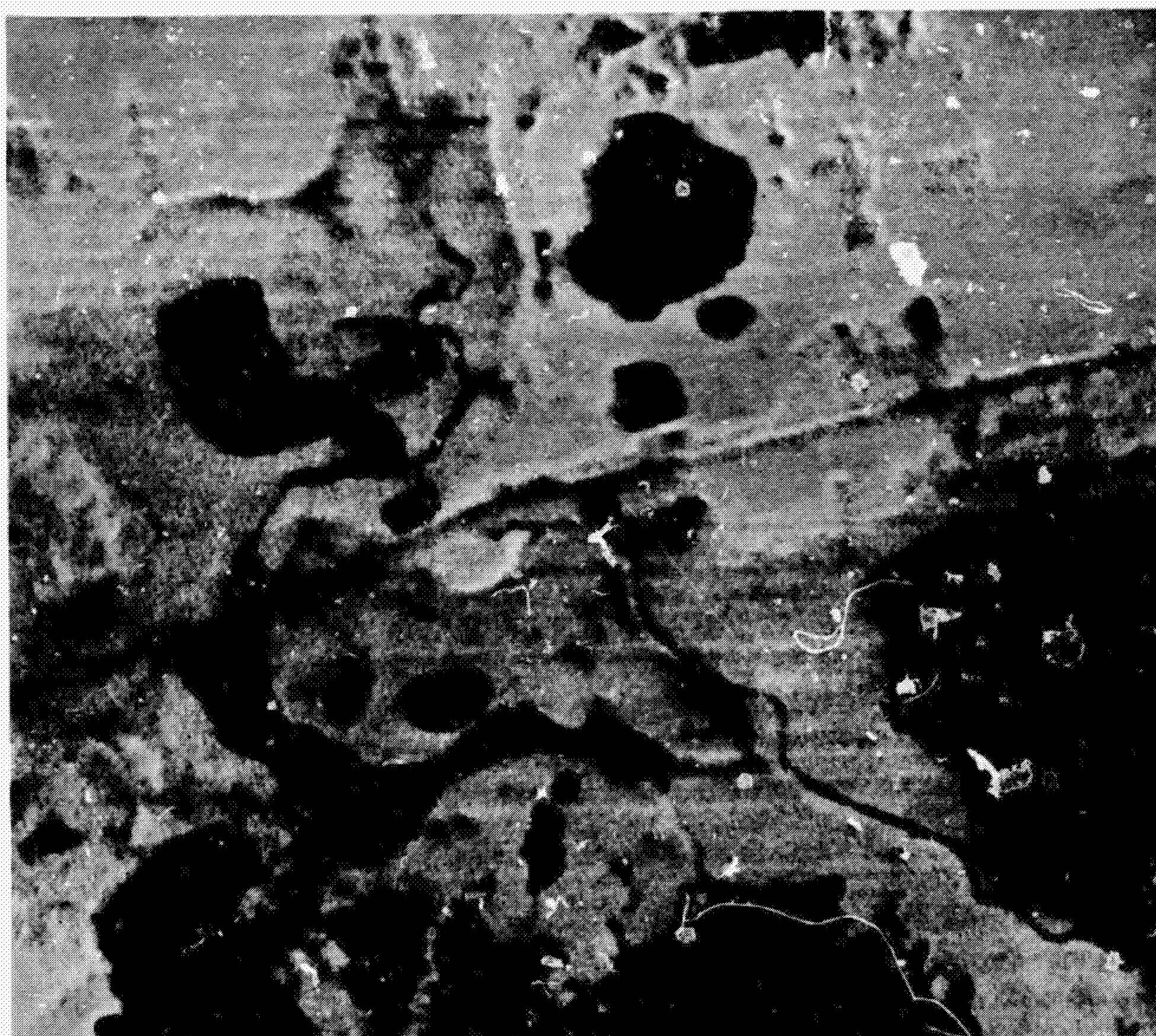


Figure 7-4.- Level II imagery of Trinity Study Site acquired August 29, 1972 (MCFV, digital, MSS bands 5 and 7, fifth-generation film). See last paragraph of page 7-4.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

Figure 7-5.- Level II imagery of Trinity Study Site acquired January 19, 1973 (MCFV, digital, MSS bands 4, 5, and 7, fourth-generation film). See last paragraph of page 7-4.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

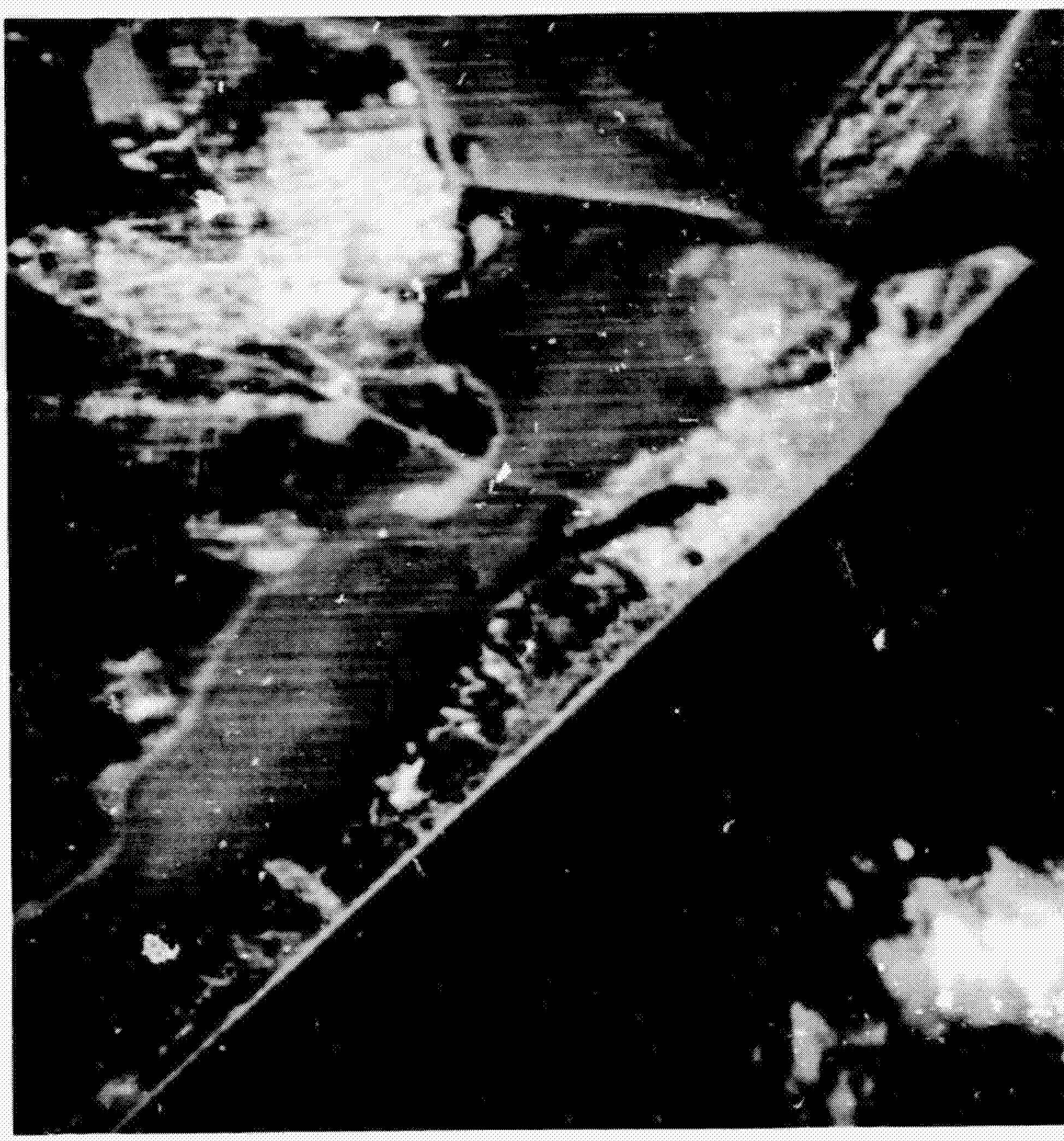


Figure 7-6.- Color composite, Galveston Study Site acquired August 29, 1972 (MCFV, analog, MSS bands 4, 5, and 7, fifth-generation film). See last paragraph of page 7-4.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-25476

Figure 7-7.- Level II imagery of Galveston Study Site acquired August 29, [illegible]2 (MCFV, digital, MSS bands 4, 5, and 6, fifth-generation film). See last paragraph of page 7-4.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-25504

Figure 7-8.- Level III imagery of Galveston Study Site acquired August 29, 1972 (MCFV, digital, MSS bands 4, 5, and 6, fifth-generation film). See last paragraph of page 7-4.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

Figure 7-9.- Level II imagery of Galveston Study Site acquired November 26, 1972 (MCFV, digital, MSS bands 5 and 6, fourth-generation film). See last paragraph of page 7-4.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

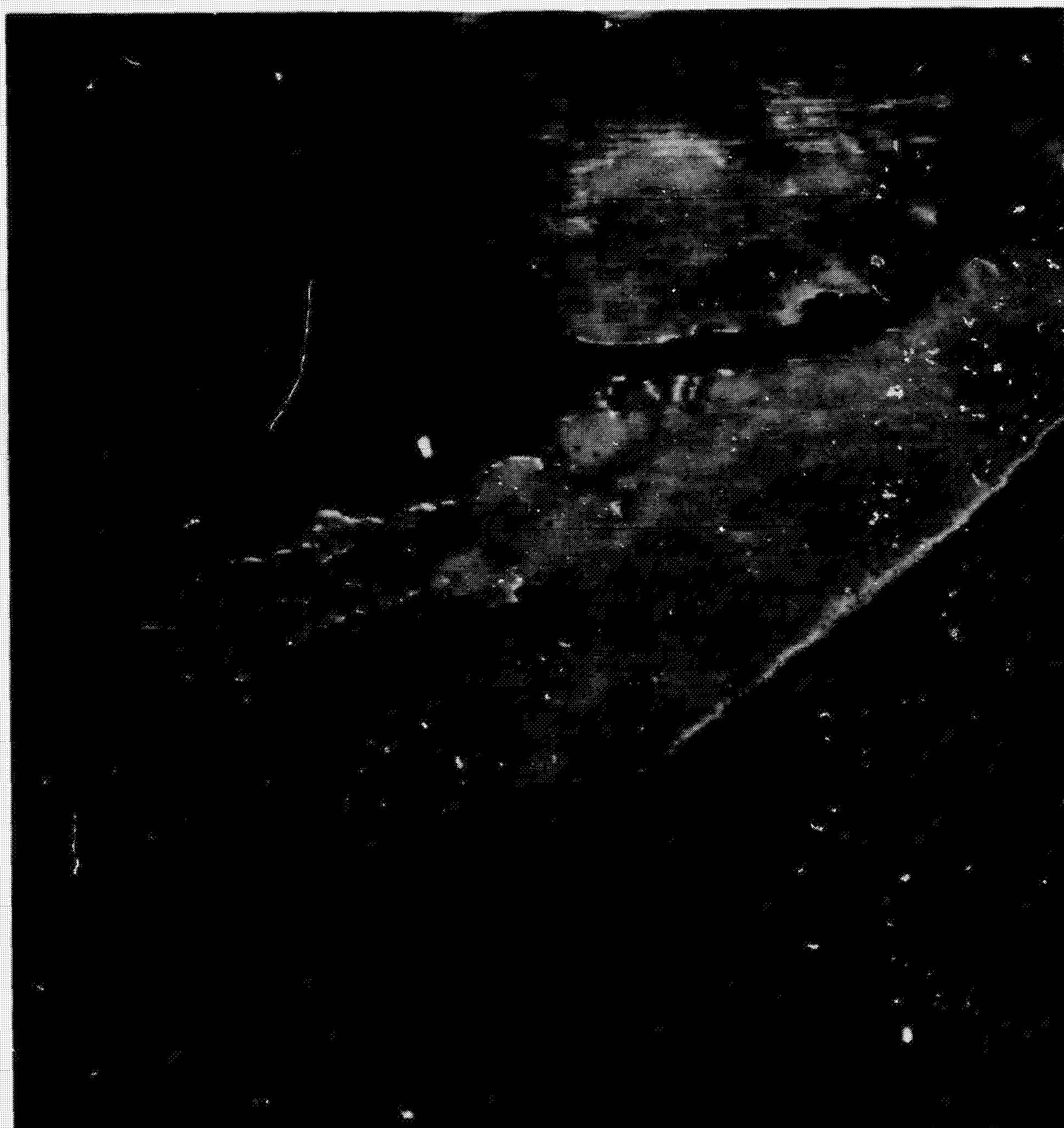


Figure 7-10.- Level I imagery of Galveston Study Site acquired October 3, 1972 (MCFV, digital MSS bands 4, 5, and 6, first-generation film). See last paragraph of page 7-4.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-25521

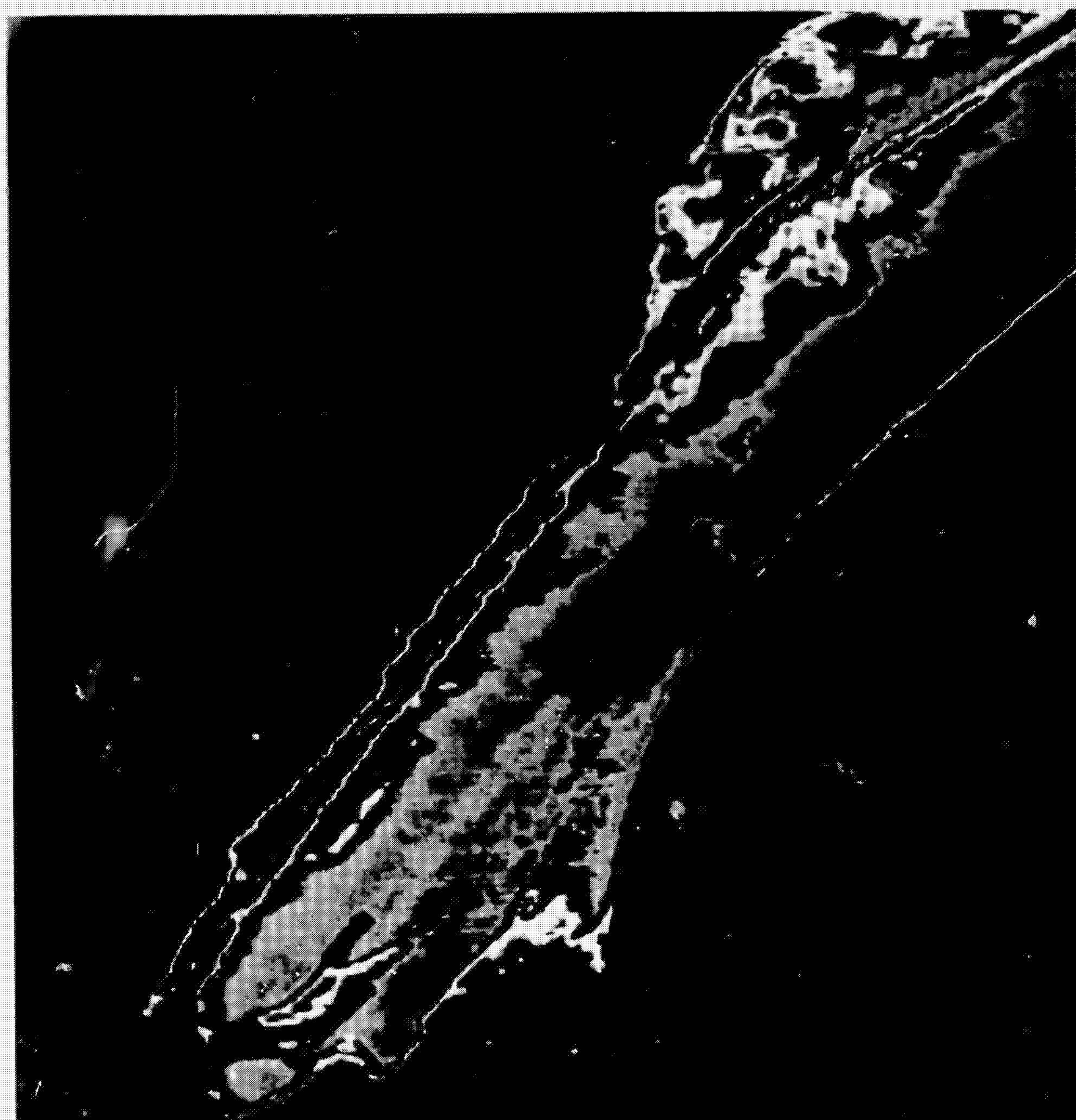


Fig ~~ 7-11.- Level III imagery of Bolivar Study Site acquired August 28, 1972 (MCFV, digital, MSS7, first-generation film). See last paragraph of page 7-4.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

Figure 7-13.- Level II imagery of Galveston and Bolivar Study Sites acquired January 19, 1973 (MCFV, digital, MSS bands 4, 5, and 7, fourth-generation film). See last paragraph of page 7-4.

8.0 COMPUTER-AIDED PROCESSING

This section describes the computer-aided techniques that were used to process digital ERTS-1 data contained on computer-compatible tapes (CCT) provided by the NASA Goddard Space Flight Center. In this regard, only system-corrected MSS CCT's were processed. Examples of the computer-aided processing are also provided. The details of the computer-aided processing techniques used in this study are given in reference 4.

The quantitative and qualitative evaluations of the data are given in section 9.0. The remainder of the imagery is given in appendix B.

8.1 COMPUTER-AIDED PROCESSING FLOW

Computer-aided processing consists of four basic activities,

a. Preprocessing
b. Pattern recognition
c. Displaying and recording
d. Postprocessing

The computer-aided processing flow used for the coastal investigation is diagrammed in figure 8-1.

8.2 PREPROCESSING

The first requirement in computer-aided processing was the conversion of the original or duplicate sensor-corrected MSS CCT from the GSFC format to the MSDS format. This

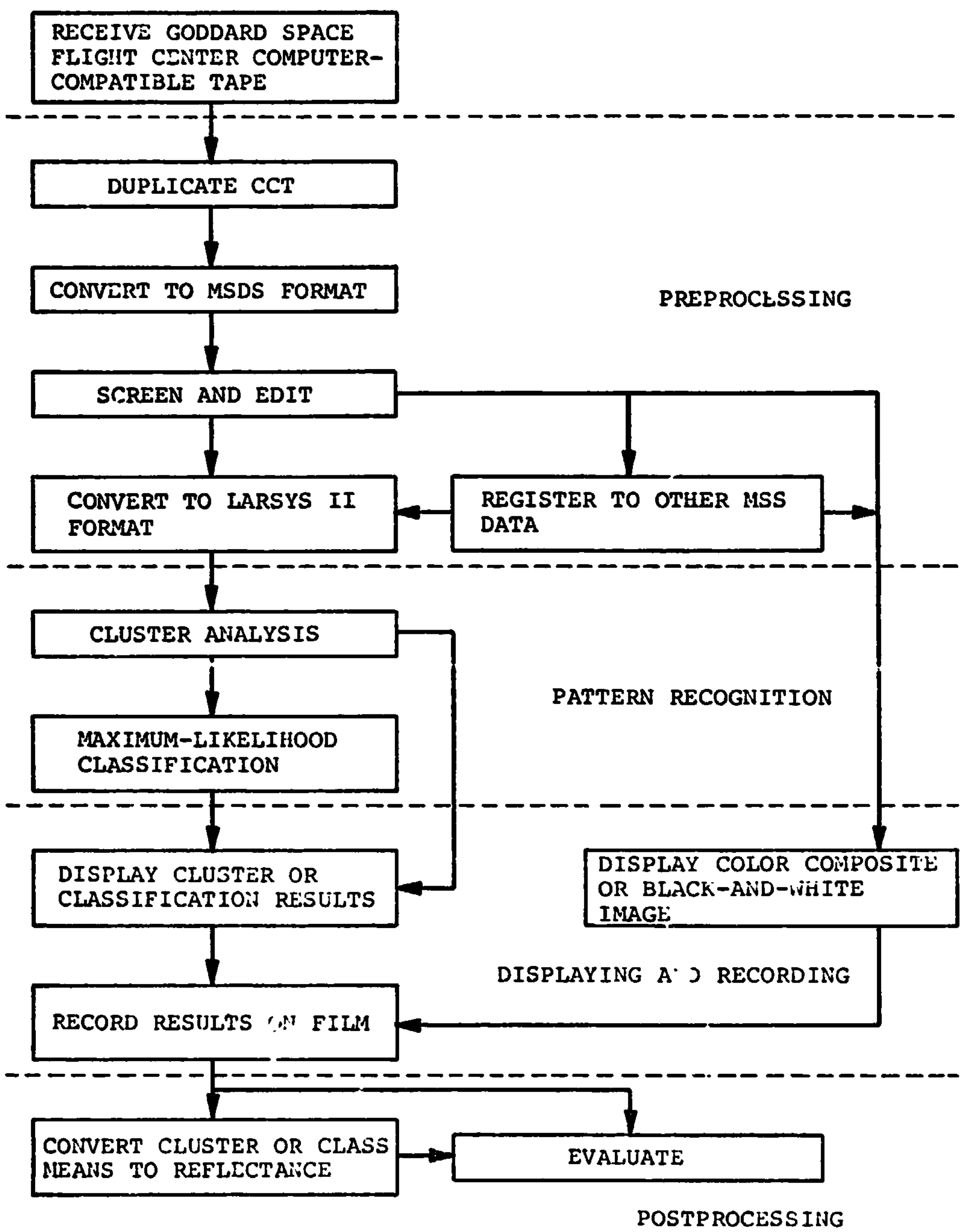


Figure 8-1.- Computer-aided processing flow.

format is compatible to the screening and editing programs on the Passive Microwave Imaging System (PMIS) Data Analysis Station (DAS) or the MSDS DAS. If the scan line and element coordinates of the study site are known at this point from previous analysis runs, resolution elements may also be edited and enlarged as part of the conversion.

The second requirement is the screening and editing of the reformatted CCT. In the screening operation, performed on a DAS, the operator mathematically operates on the data in its original grayscale values to enhance the screened data. The original grayscale value, L_o , is transformed to a new grayscale value, L_n , given by $G(L_o + B)$, where G is a multiplication factor and B is an offset factor. Since the screening programs use the full range of available color intensities on the cathode-ray tubes (CRT) to represent grayscale values (after the mathematical operation has been applied) from 0 to 255, the original ERTS-1 data may be enhanced in many ways. The parameter G is limited to the range 0 to 10. Thus, with a G factor of up to 10, as few as 26 grayscale values may be represented by the full range of color intensities of the DAS CRT's. Since the original grayscale values in the ERTS-1 CCT's are usually in the range of 0 to 127 in MSS bands 4, 5, and 6 and in the range of 0 to 63 in MSS band 7, multiplication factors of 2.0 and 4.0, respectively, are used to screen the ERTS-1 data. If a histogram of the grayscale value population is available for each band, then optimum G and B factors may be set up for the screening. This procedure is desirable if color composite or black-and-white images are to be recorded on film by the DAS.

In the editing process, a rectangular cursor may be displayed about a portion of the data being screened on the DAS-CRT and the DAS may be instructed to edit the portion of the whole data set onto another CCT in the same MSDS format.

A third step is the conversion of the edit CCT to LARSYS II format, which is the format required by the pattern recognition programs in the UNIVAC 1108. This conversion is made on the MSDS DAS.

An option after the screen-and-edit operation and before the conversion to the LARSYS II format is the registration of one set of ERTS-1 data to another set of ERTS-1 data. This option was used to create an eight-band CCT from two four-band CCT's. In particular, the Trinity Study Site data acquired on August 28 and November 26, 1972, were processed in this manner. Temporal analyses and change detection analyses were performed on the registered data sets by computer-aided means.

A branch in the processing was made at the screen-and-edit point or registration point (figure 8-1). In this branch, a color or black-and-white image may be displayed from the digital data and the results recorded on film. In this manner, a first-generation grayscale image of a study site may be produced as sensed in any particular band of ERTS-1 data. These grayscale images can then be processed further by the conventional additive color techniques described in this section. Contrast enhancements of a particular band of ERTS-1 digital data may also be produced on film. In this process, various colors are used to record

the levels of grayscale values in the ERTS-1 data. Finally, three color images may be produced of three bands of ERTS-1 data. Usually, these color composites are set up to simulate a color infrared photograph; i.e., blue is used for MSS4, green for MSS5, and red for MSS6 or 7. Examples of the color composites are shown in figures 8-2 through 8-4.

Land and water areas are separable in the figures. The only wetland areas that are clearly seen in the figures are the salt marsh (dark brown) in the Galveston and Bolivar Study Sites. Fresh and brackish marsh areas in the Trinity Study Site do not appear spectrally different from nonmarsh areas except water (blue) and forest (dark red). Nonvegetated wetland areas in the Galveston area appear blue on the color composite and are not separable from some turbid or shallow water areas. Sand, concrete, and shell areas (highways, dams, beaches, industrial areas) appear uniquely as white in the figures. Swamp appears similar to forest. The inconsistency from scene to scene due to slightly different settings on the DAS and lack of controlled film processing made it difficult to develop color keys for the composites.

Other examples of color composites and of contrast enhancements are given in appendix B.

8.3 PATTERN RECOGNITION PROCESSING

In general, two pattern recognition capabilities available at the NASA Johnson Space Center were used.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28090

Figure 8-2.- Color composite of Trinity Study Site acquired October 3, 1972 (PMIS DAS, MSS bands 4, 5, and 7).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

Figure 8-3.- Color composite of Galveston Study Site (mirror image) acquired October 3, 1972 (PMIS DAS, MSS bands 4, 5, and 7).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28083

Figure 8-4.- Color composite of Bolivar Study Site acquired October 3, 1972 (PMIS DAS, MSS bands 4, 5, and 7).

8.3.1 Clustering

The first pattern recognition capability used was clustering. Two algorithms were available at the onset of the coastal investigation. The first was ISOCLS on the UNIVAC 1108, and the second was NSCLAS, available on the remote terminal at NASA/JSC, which is tied to an IBM 360/44 at Purdue University.

The task of each clustering algorithm was to define the means or centers of spectral clusters in multichannel, registered data sets. A cluster is located in multichannel space so that it is usually associated with a spectrally homogeneous feature in the scene.

The ISOCLS algorithm is iterative, and the controls consist of the maximum number of clusters to be defined (MAXCLS), the maximum allowable standard deviation (STDMAX), a separability parameter (DLMIN), and the maximum number of allowable iterations (ISTOP).

Since one maximum allowable standard deviation criterion was used for all channels of data and all clusters, ISOCLS tended to produce clusters with uniform dimensions in all channels and for all clusters. Thus, some study features in the scene may be represented by several clusters or subclusters.

The NSCLAS cluster algorithm operates in a simpler manner than the ISOCLS algorithm. After setting up a number of initial cluster centers, the points are assigned to clusters as in ISOCLS. Then new means are calculated. The

sequence is repeated until no change is observed in the number of points assigned to each cluster.

The Coastal Analysis Team used a very convenient diagram for use in identification of clusters. This diagram is a cluster or class diagram, differentiated according to the type of pattern recognition results being analyzed. The diagram is a simple plot of the location of clusters or classes in MSS band 4 versus the location in MSS band 7. This allows the analyst to identify clusters as belonging to a given level of feature classification by relating its position to other defined clusters. This diagram is given for all data sets that have been generated during the two analysis cycles. In general, many coastal features cluster centers were observed to occupy the same position relative to other features so that the plot of information in MSS bands 4 and 7 represented a triangle-shaped area (dashed lines) in which the vertices of the triangle represented three homogeneous types of features: water, dry vegetation (grass and trees), and nonvegetated dry areas (shown ideally in figure 8-5). Cluster centers within the triangle represented mixtures of these three general types of features. For example, marsh clusters fell between dry vegetation clusters and water clusters, and nonvegetated wetland clusters fell between water clusters and nonvegetated dry clusters. Swamp clusters tended to fall between water clusters and forest clusters.

8.3.2 Maximum Likelihood Classification

The second pattern-recognition capability was the maximum-likelihood classification. In this technique, the

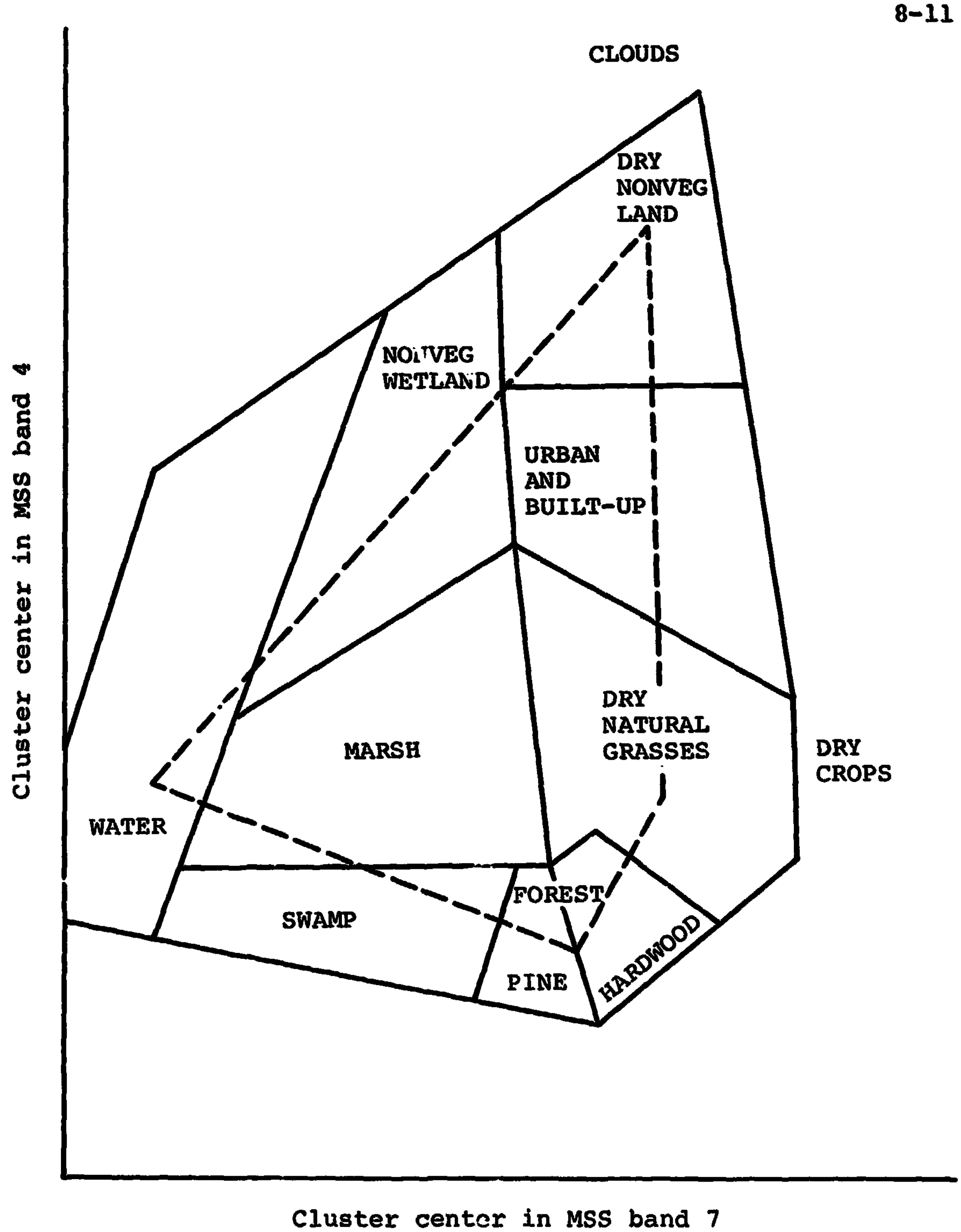


Figure 8-5.– Schematic class or cluster diagram and typical identifications.

analyst defined areas in the image known as training fields. For each field he assigned a field name, a class name, and a class symbol. More than one training field may be defined for a class. In addition, the analyst may define test fields and one or more large areas to be classified. The maximum-likelihood algorithm available at the NASA Johnson Space Center is the LARSYS program, developed by the Laboratory for Applications of Remote Sensing at Purdue University.

In the LARSYS algorithm, the means for each channel and covariance matrices among channels were calculated for each class from the data inscribed in the defined training fields. Then, assuming a Gaussian distribution of points about the mean, the algorithm calculated the conditional probability density function. A point was assigned to the class in which the conditional probability density function was largest. The percentage of points that were to be unclassified due to their spectral distance from the class mean was controlled by use of a threshold parameter. The threshold percentage represents different threshold distances in each channel and for each class. If the threshold distance was exceeded for the most likely class, then the point was assigned to the nonclassified group (the threshold class).

8.4 DISPLAYING AND RECORDING

After the data had been analyzed by the use of pattern recognition programs, it was necessary to display the results and make a film record of them. The CCT that is produced by the various pattern recognition programs discussed above can be read and processed by a color study program and filmed on the PMIS DAS. Also, unprocessed MSDS formatted CCT's

may be read, processed, and filmed on the PMIS DAS (section 8.2).

The input tape to the PMIS DAS color study program consisted of one channel of data in which the data values corresponded to the multichannel resolution elements on the original ERTS-1 edit tape. In the channel, a range of values from 1 to 64 was used to represent each subcluster or class that was defined by the pattern recognition program. The analyst set up a color table so that the results of the pattern recognition operation were displayed in various colors on the PMIS-DAS cathode-ray tube. Since the analyst may use the same color to represent a number of subclusters or subclasses, it was possible to construct several levels of information on several strips of film from one set of pattern recognition results. Toward this end, a set of standard colors was selected to represent Levels I and II, coastal study features. These colors are listed in table 8-I.

8.5 EARTH RESOURCES INTERACTIVE PROCESSING SYSTEM

The ERIPS is a data processing system that operates in real-time and is capable of accepting GSFC-formatted or LARSYS II-formatted data. In general, ERIPS has been used to screen ERTS-1 data, to edit the data over the coastal study sites, to define training fields, to generate statistics (means and covariances) for the LARSYS algorithm, and to create a batch processing input data tape for LARSYS implemented on a separate CYBER 73 computer. Also, ERIPS was used to perform a real-time trial classification over a portion of the study site and to register multispectral

TABLE 8-I.- STANDARD COLOR CODE FOR DIGITAL PROCESSING RESULTS DISPLAY

Level	Study Feature	Color Code
I	a. Water	Blue
	b. Wetland	Yellow
	c. Land	Red
II Water	a. Water Masses	Blue-Light Brown
II Wetland	a. Swamp	Purple
	b. Marsh	Yellow
	c. Nonvegetated Wetland	Brown
II Land	a. Land, Sand	White
	b. Barrier Flat Vegetation, Grassland	Green
	c. Forest	Red
	d. Other	Black

scanner (MSS) data to a reference grid or to other MSS data acquired over the same study site. When ERIPS, CYBER 73, and the PMIS DAS are working properly and are available in the proper timing, the entire preprocessing, pattern recognition, displaying, and recording operations for a data set may be completed in one working day. In practice, the entire procedure required about 2 weeks to complete.

8.6 POSTPROCESSING

After the pattern recognition operations have been performed on the ERTS-1 data and the results have been recorded on film, these output products must be evaluated in a postprocessing operation (figure 8-1).

To determine the spectral uniqueness and temporal properties of study features, the cluster or class means produced by the pattern recognition algorithms must be converted to reflectance values for each ERTS-1 band. This operation was performed by the use of information calculated by the atmospheric correction algorithm ROTAR (Reconstruction of Target Radiance).

Test fields were defined in the scenes to evaluate the classification accuracies of the pattern recognition algorithms. This was done manually and the accuracies were calculated on desk calculators. Another measure of classification accuracy was the comparison of the areal extent of a particular feature area as determined from aircraft photography and ERTS-1 data.

It was also necessary to evaluate the detectability of the study features in the images produced by the pattern recognition programs and the display and recording devices. This evaluation was qualitative and involved image interpretation. These qualitative evaluations are given in section 9.0. The quantitative evaluations (classification accuracy, areal measurement accuracy, and spectral reflectance signature evaluations) are also given in section 9.0.

8.6.1 Conversion from Grayscale to Reflectance Values Using ROTAR

An atmospheric correction algorithm (ROTAR) was used to obtain a table of target reflectance values (Lambertian reflection) versus grayscale values for each MSS band. These values were obtained for a given zenith sun angle and aerosol (haze) condition. ROTAR used the results of a direct solution to the radiative transfer problem for a given surface and atmospheric condition under the following basic assumptions:

a. Rayleigh scattering gaseous layer over Mie scattering aerosol layer

b. Plane, parallel two-layer atmosphere

c. Cloud-free atmosphere

d. Infinite Lambertian surface

The direct solution used the doubling technique and was exact for the assumed conditions; i.e., it included all levels of multiple scattering effects. In a sense, the ROTAR program uses a tabular function of grayscale value versus surface Lambertian reflectance to allow a given cluster means (grayscale mean value) to be interpreted in

terms of the effective Lambertian reflectance of the surface. This relationship is almost linear, which permits a linear best fit to be made to the tabular values of reflectance versus grayscale value for each MSS band. This linear best fit can also be made for each data set date in which the zenith sun angle and aerosol amount are known. The zenith sun angle is given on the GSFC film images of the ERTS-1 data. The aerosol amount is measured from the ground by a multichannel sun photometer at the time of the ERTS-1 overpass. In some cases, the aerosol amount must be estimated from nonsynoptic measurements or from measurements made near the study site. In any case, the effect of errors in estimating the aerosol amount on the relationship between the reflectance and grayscale values was generally significant only for MSS bands 4 and 5.

The actual linear relationship between the surface reflectance R_i and the grayscale value L_i for each *ith* band and for each site and date analyzed in this report is given in table 8-II, along with other parameters of interest. In this table, the reflectance of the surface in the *ith* ERTS-1 band is calculated by the expression $R_i = b_i L_i - a_i$. This calculation is performed by a program on a desk calculator.

8.6.2 Areal Measurement Technique

To achieve the highest possible accuracy in the measurement of water and marsh areas in the coastal study sites, an objective technique had to be developed to measure areas using the results of cluster analysis.

TABLE 8-II.- CONSTANTS FROM ROTAR ANALYSIS FOR CONVERSION OF ERTS-1 GRAYSCALES TO SURFACE REFLECTANCE

Date	Site	Aerosol Optical Depth	Zenith Sun Angle	ERTS-1 Band, i	a_i	b_i	Standard Error e_i*
8/28&29/72	All	0.35	34°	MSS4	7.07	0.433	0.35
				MSS5	4.15	0.395	0.26
				MSS6	2.79	0.423	0.25
				MSS7	1.68	1.059	0.28
10/3/72	Trinity	0.12	43°	MSS4	5.10	0.476	0.28
				MSS5	2.68	0.436	0.17
				MSS6	1.64	0.471	0.15
				MSS7	0.83	1.188	0.17
10/3/72	Galveston	0.28	43°	MSS4	6.71	0.490	0.37
				MSS5	3.82	0.447	0.27
				MSS6	2.49	0.480	0.25
				MSS7	1.36	1.198	0.30
11/26/72	Trinity	0.12	56°	MSS4	5.60	0.643	0.54
				MSS5	3.03	0.59	0.32
				MSS6	1.85	0.637	0.26
				MSS7	0.87	1.600	0.29
11/26/72	Galveston	0.20	56°	MSS4	6.59	0.6555	0.65
				MSS5	3.76	0.600	0.41
				MSS6	2.38	0.641	0.35
				MSS7	1.16	1.611	0.40

*e_i = standard error on R_i

At the boundary of a homogeneous feature such as water or salt marsh, the ERTS-1 MSS resolution elements were expected to overlap on both water or marsh areas and on adjacent nonwater or nonmarsh areas. The overall grayscale value of a boundary resolution element would be the result of an area-wide mixture of the subject feature and its neighboring features.

The distinction between water or marsh areas and surrounding dry areas was greatest in MSS band 7 (λ810 to 990 nm). Thus, if for a given date (sun angle and seasonal effects constant) a mean grayscale value can be defined for water, salt marsh, and other features as a group in MSS band 7, salt marsh versus other features can be assigned by area. Thus, assuming that only resolution elements adjacent to subject feature resolution elements lay on the boundary of the subject feature, the number of percentage resolution elements lying at or on the boundary of subject features could be counted accurately by a simple summation procedure. This technique was used to make measurements of the areal extent of water bodies and particular salt marsh areas in the Trinity and Galveston study sites and for the August 29, 1972, ERTS-1 overpass.

8.7 CLUSTERING PRODUCTS

This section presents examples of the products (cluster maps) produced by the ISOCLS clustering algorithm and the PMIS DAS display and film recording system. Supplemental cluster maps are given in appendix B for the reader who wishes to study these products in greater detail. In general, Levels I, II, and III maps were made for each clust - analysis of each set of data. Only the maps that show the

Level I water and Level II wetland and land features are shown in this section for the most part. Other types of cluster maps are given to illustrate a particular capability or failure in the cluster analyses.

Table 8-III gives the pertinent control factors and other data for each cluster analysis performed. The resulting cluster means and cluster identities are given in tables 8-IV through 8-XVII. The associated cluster diagrams are given in figures 8-6 through 8-12. Examples of the cluster maps are given in figures 8-13 through 8-23, and other cluster maps are given in appendix B.

8.8 MAXIMUM LIKELIHOOD CLASSIFICATION PRODUCTS

This section presents the results of the classification of study features through the use of training fields and from the use of the LARSYS maximum likelihood classification algorithm that is available on the ERIPS-CYBER 73 system.

In this system the analyst displays one channel of ERTS-1 data over his site on the ERIPS and defines training fields for a number of feature classes. The ERIPS then is commanded to complete the training field statistics and to prepare a batch system (CYBER-73) run for the maximum likelihood classification of the study site through the use of the LARSYS algorithm. The output of the LARSYS CYBER-73 run is a printout and a CCT in color-study format. The CCT is processed by the color-study display program on the PMIS DAS, and the results are filmed in color.

TABLE 8-III.- CONSTRAINTS FOR ISOCLS CLUSTERING ANALYSIS

Study Site	Date	MAXCLS	STDMAX	DLMIN	Estimated Number of Iterations	Number of Actual Clusters
Trinity	Aug. 29, 1972	32	2.0	3.2	25	30
Trinity	Oct. 3, 1972	32	2.5	3.0	25	32
Trinity	Nov. 26, 1972	30	2.5	3.0	35	27
Galveston	Aug. 29, 1972	25	3.0	1.0	12	25
Galveston	Oct. 3, 1972	25	1.5	1.0	12	25
Galveston	Nov. 26, 1972	30	1.9	1.0	12	30
Bolivar	Aug. 28, 1972	30	2.3	3.0	15	22

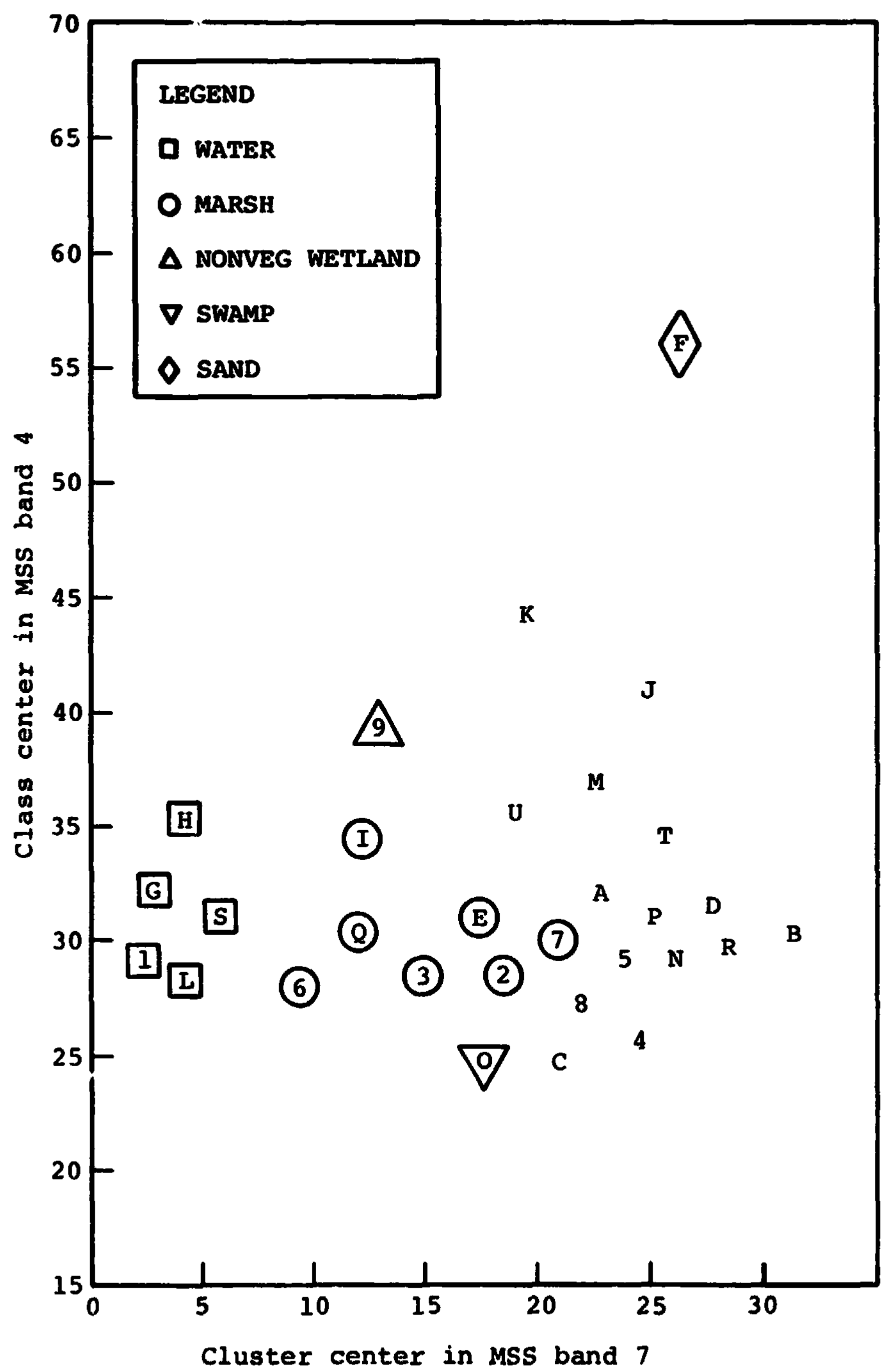
TABLE 8-IV.- CLUSTER IDENTITIES, TRINITY STUDY SITE, AUGUST 29, 1972

Cluster Symbol	Cluster Identity
1	Water
2	High marsh, rice field
3	Marsh
4	Deciduous forest
5	Dry grassland
6	Marsh
7	High marsh
8	Dry grassland
9	Nonvegetated wetland
A	Dry grassland
B	Dry grassland
C	Pine forest
D	Dry grassland
E	High marsh
F	Concrete, sand
G	Water
H	Water
I	Marsh
J	Mixed bare soil and vegetation
K	Mixed bare soil and vegetation
L	Water (algae mat covered)
M	Mixed bare soil and vegetation
N	Dry grassland
O	Swamp
P	Dry grassland
Q	Marsh
R	Dry grassland
S	Water (algae mat)
T	Dry grassland
U	Mixed bare soil and vegetation

TABLE 8-V.- CLUSTER MEANS, TRINITY STUDY SITE, AUGUST 29, 1972

Cluster Symbol	Cluster Means*							
	MSS4		MSS5		MSS6		MSS7	
1	29.16	(5.56)	19.49	(3.55)	12.12	(2.34)	2.34	(0.8)
2	28.46	(5.26)	20.55	(3.97)	35.46	(12.21)	18.28	(17.68)
3	28.48	(5.26)	20.78	(4.06)	30.54	(10.13)	14.71	(13.9)
4	25.82	(4.11)	16.20	(2.25)	42.04	(14.99)	24.22	(23.97)
5	29.29	(5.61)	20.67	(4.01)	43.56	(15.64)	23.60	(23.31)
6	28.30	(5.18)	20.43	(3.92)	23.61	(7.2)	9.28	(8.15)
7	29.99	(5.92)	22.24	(4.63)	39.52	(13.93)	20.64	(20.18)
8	27.31	(4.76)	19.07	(3.38)	39.72	(14.01)	21.67	(21.27)
9	39.15	(9.88)	35.09	(9.71)	32.76	(11.07)	12.47	(11.53)
A	32.01	(6.79)	15.02	(5.73)	42.59	(15.23)	22.51	(22.16)
B	30.38	(6.08)	20.07	(3.78)	57.58	(21.57)	30.98	(31.13)
C	24.75	(3.65)	14.72	(1.66)	36.35	(12.59)	20.75	(20.29)
D	31.52	(6.58)	22.94	(4.91)	50.38	(18.52)	27.44	(27.33)
E	30.94	(6.33)	24.20	(5.41)	34.65	(11.87)	17.16	(16.49)
F	55.94	(17.15)	57.84	(18.7)	58.69	(22.04)	26.03	(25.89)
G	32.17	(6.86)	23.61	(5.18)	14.14	(3.19)	2.74	(1.22)
H	35.44	(8.28)	29.09	(7.84)	19.16	(5.81)	4.05	(2.61)
I	34.30	(7.78)	25.44	(5.9)	29.43	(9.66)	11.97	(11.00)
J	40.99	(10.68)	38.10	(10.9)	50.67	(18.64)	24.77	(24.55)
K	44.18	(12.06)	42.86	(12.78)	44.29	(15.94)	19.29	(18.75)
L	28.39	(5.22)	20.71	(3.83)	16.69	(4.27	3.92	(2.47)
M	36.96	(8.93)	32.03	(8.5)	44.47	(16.02)	22.13	(21.76)
N	29.18	(5.56)	20.04	(3.77)	47.58	(17.34)	25.94	(25.79)
O	24.90	(3.71)	15.40	(1.93)	31.34	(10.47)	17.29	(16.63)
P	31.01	(6.36)	23.09	(4.97)	45.63	(16.51)	24.92	(24.71)
Q	30.29	(6.05)	22.97	(4.92)	27.92	(9.02)	11.78	(10.8)
R	29.71	(5.79)	19.93	(3.72)	52.36	(19.36)	28.12	(28.1)
S	31.10	(6.40)	23.82	(5.20)	20.42	(15.86)	5.65	(4.3)
T	34.64	(7.93)	28.37	(7.06)	47.83	(17.44)	25.22	(25.03)
U	35.67	(8.38)	31.35	(8.23)	39.39	(13.87)	18.88	(18.31)

*The numbers in parentheses are reflectances (%).



F··ure 8-6.- Cluster diagram of Trinity Study Site imagery acquired August 29, 1972.

TABLE 8-VI.- CLUSTER IDENTITIES, TRINITY STUDY SITE, OCTOBER 3, 1972

Cluster Symbol	Cluster Identity
1	Water
2	Water
3	Water
4	Nonvegetated wetland
5	Marsh
6	Nonvegetated wetland
7	Marsh, rice fields
8	Sand, bare soil
9	Marsh, rice fields
A	Swamp
B	Bare soil
C	Mixed bare soil and vegetation
D	Marsh
E	Dry grassland
F	Pine forest
G	Mixed bare soil and vegetation
H	Dry grassland
I	Deciduous forest
J	Dry grassland
K	Concrete, bare soil, sand
L	Urban (residential)
M	Dry grassland
N	Dry grassland
O	Mixed bare soil and vegetation
P	Mixed concrete and vegetation
Q	Dry grassland
R	Bare soil, concrete
S	Dry grassland
T	Urban (residential)
U	Urban (bright), shell, bare soil
V	Dry grassland
W	Urban (residential)

TABLE 8-VII.- CLUSTER MEANS, TRINITY STUDY SITE, OCTOBER 3, 1972

Cluster Symbol	Cluster Means*			
	MSS4	MSS5	MSS6	MSS7
1	25.22 (6.9)	14.32 (3.56)	7.98 (2.12)	1.04 (0.41)
2	26.73 (7.62)	16.92 (4.7)	10.61 (3.36)	1.70 (1.19)
3	31.37 (9.83)	24.66 (8.07)	14.04 (4.97	2.23 (1.82)
4	32.26 (10.26)	25.31 (8.36)	21.16 (8.33)	6.92 (7.39)
5	25.86 (7.21)	17.54 (4.97)	18.98 (7.3)	7.56 (8.15)
6	36.59 (12.32)	31.09 (10.88)	27.17 (8.33)	9.52 (10.48)
7	27.12 (7.81)	20.11 (6.09)	26.27 (10.73)	12.86 (14.45)
8	37.38 (12.69)	33.42 (11.89)	33.14 (13.97)	14.33 (16.19)
9	30.26 (9.3)	25.73 (8.54)	28.76 (11.91)	14.45 (16.34)
A	24.93 (6.77)	15.87 (4.24)	27.88 (11.49)	14.77 (16.72)
B	42.39 (15.08)	40.53 (14.99)	39.36 (16.9)	16.89 (19.24)
C	33.24 (10.72)	29.42 (10.15)	35.06 (14.87)	17.54 (20.01)
D	26.87 (7.69)	19.03 (5.62)	32.83 (13.82)	17.75 (20.26)
E	29.46 (8.92)	23.59 (7.61)	34.57 (14.64)	18.26 (20.86)
F	23.03 (5.86)	13.57 (3.24)	31.74 (13.31)	18.98 (21.72)
G	36.62 (12.33)	33.05 (11.73)	40.65 (17.51)	19.95 (22.87)
H	27.65 (8.06)	20.27 (6.16)	37.36 (15.96)	20.44 (23.45)
I	24.10 (6.37)	14.45 (3.62)	35.66 (15.16)	21.01 (24.13)
J	30.88 (9.6)	24.89 (8.17)	39.29 (16.87)	21.03 (24.15)
K	44.55 (16.11)	44.19 (16.59)	46.34 (20.19)	21.14 (24.28)
L	33.94 (11.06)	28.13 (9.58)	42.89 (18.56)	22.44 (25.83)
M	28.82 (8.62)	21.63 (6.75)	41.16 (17.75)	22.52 (25.92)
N	26.49 (7.51)	17.63 (5.01)	40.27 (17.33)	22.80 (26.26)
O	38.45 (13.2)	35.02 (12.59)	45.58 (19.83)	22.65 (26.08)
P	42.57 (15.16)	40.86 (15.13)	51.31 (22.53)	25.08 (28.97)
Q	28.00 (8.23)	19.76 (5.94)	45.14 (19.62)	25.16 (29.06)
R	51.98 (19.64)	53.73 (20.75)	53.50 (23.56)	23.62 (27.23)
S	31.03 (9.67)	24.15 (7.85)	44.03 (19.1)	24.10 (27.8)
T	35.49 (11.79)	28.95 (9.94)	47.38 (20.68)	25.26 (29.18)
U	67.60 (27.08)	71.37 (28.44)	66.12 (29.5)	28.10 (32.55)
V	31.26 (9.78)	23.44 (7.54)	48.68 (21.29)	27.19 (31.47)
W	36.95 (12.49)	29.33 (10.11)	53.26 (23.45)	28.36 (32.86)

*The figures in parentheses represent reflectances (%).

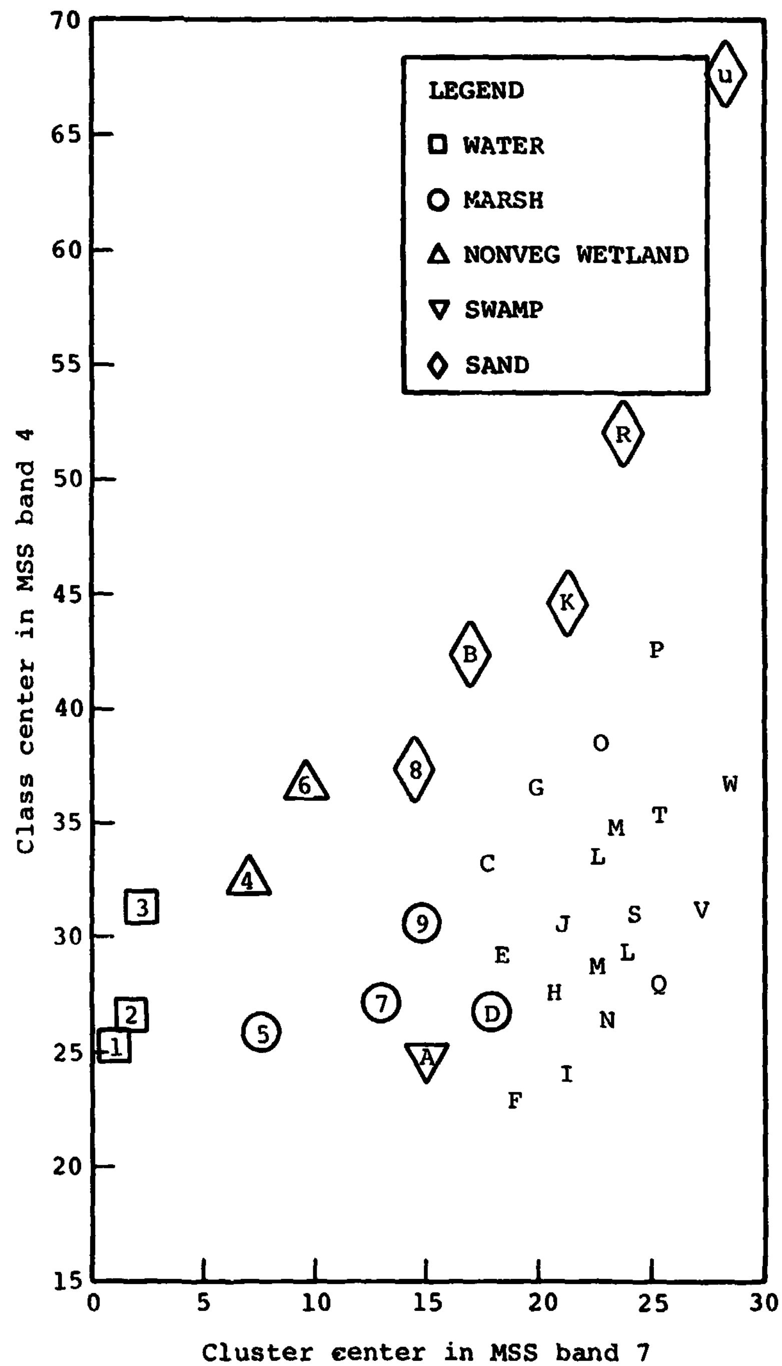


Figure 8-7.- Cluster diagram of Trinity Study Site imagery acquired Octobr 3, 1972.

TABLE 8-VIII.- CLUSTER IDENTITIES OF TRINITY STUDY SITE (IMAGERY ACQUIRED NOVEMBER 26, 1972)

Cluster Symbol	Cluster Identity
1	Water
2	Water
3	Water
4	Water
5	Water
6	Water
7	Nonvegetated wetland
8	Swamp, marsh, rice fields
9	Marsh, rice fields
A	Marsh, rice fields
B	Dry grassland
C	Mixed bare soil and vegetation
D	Pine forest
E	Concrete, urban (bright), bare soil
F	Mixed bare soil and vegetation
G	Deciduous forest
H	Sand, bare soil
I	Dry grassland
J	Sand
K	Urban (residential)
L	Dry grassland
M	Urban (residential)
N	Urban (residential)
O	Dry grassland
P	Concrete, bare soil
Q	Urban (residential)
R	Dry grassland

TABLE 8-IX.- CLUSTER MEANS OF TRINITY STUDY SITE
(IMAGERY ACQUIRED NOVEMBER 26, 1972)

Cluster Symbol	Cluster Means*			
	MSS4	MSS5	MSS6	MSS7
1	18.85 (6.52)	10.39 (3.1)	5.16 (1.44)	0.43 (0.0)
2	21.55 (8.26)	13.86 (5.15)	7.42 (2.88)	0.74 (0.31)
3	24.85 (10.38)	18.89 (8.12)	11.10 (5.22)	1.66 (1.79)
4	27.35 (11.99)	24.03 (11.15)	14.81 (7.58)	2.45 (3.05)
5	28.75 (12.89)	27.36 (13.11)	18.07 (9.66)	3.02 (3.96)
6	31.52 (14.67)	31.55 (15.58)	22.76 (12.65)	4.71 (6.67)
7	27.76 (12.25)	24.42 (11.38)	22.34 (12.38)	8.53 (12.78)
8	19.69 (7.06)	14.35 (5.44)	17.21 (9.11)	8.84 (13.27)
9	23.36 (9.42)	19.26 (8.33)	20.00 (10.89)	9.52 (14.36)
A	20.17 (7.37)	15.02 (5.83)	21.78 (12.02)	12.34 (18.87)
B	21.99 (8.54)	18.26 (7.74)	24.63 (13.84)	13.69 (21.03)
C	25.03 (10.49)	21.76 (9.81)	26.15 (14.81)	13.85 (21.29)
D	17.83 (5.86)	10.93 (3.42)	22.76 (12.65)	14.07 (21.64)
E	32.57 (15.34)	30.98 (15.25)	31.73 (18.36)	14.67 (22.6)
F	27.41 (12.02)	25.53 (12.03)	29.64 (17.03)	15.47 (23.88)
G	20.23 (7.41)	14.78 (5.69)	26.37 (14.95)	15.83 (24.46)
H	37.31 (18.39)	36.55 (18.53)	34.51 (20.13)	15.37 (23.72)
I	23.04 (9.21)	19.55 (8.5)	28.40 (16.24)	16.53 (25.58)
J	43.56 (22.41)	46.31 (24.29)	42.50 (25.22)	17.75 (27.53)
K	29.27 (13.22)	26.15 (12.4)	38.72 (22.81)	21.53 (33.58)
L	21.57 (8.27)	16.79 (6.88)	30.31 (17.46)	18.20 (28.25)
M	25.07 (10.52)	21.35 (9.57)	31.54 (18.24)	18.35 (28.49)
N	28.52 (12.74)	26.06 (12.35)	34.00 (18.81)	18.36 (28.51)
O	23.14 (9.28)	18.83 (8.08)	33.41 (19.43)	19.98 (31.1)
P	35.06 (16.94)	34.41 (17.27)	40.29 (23.81)	20.18 (31.42)
Q	25.76 (10.96)	21.11 (9.42)	37.49 (22.03)	21.78 (33.93)
R	22.90 (9.12)	16.86 (6.92)	37.81 (22.23)	22.50 (35.13)

*The numbers in parentheses represent reflectances (%).

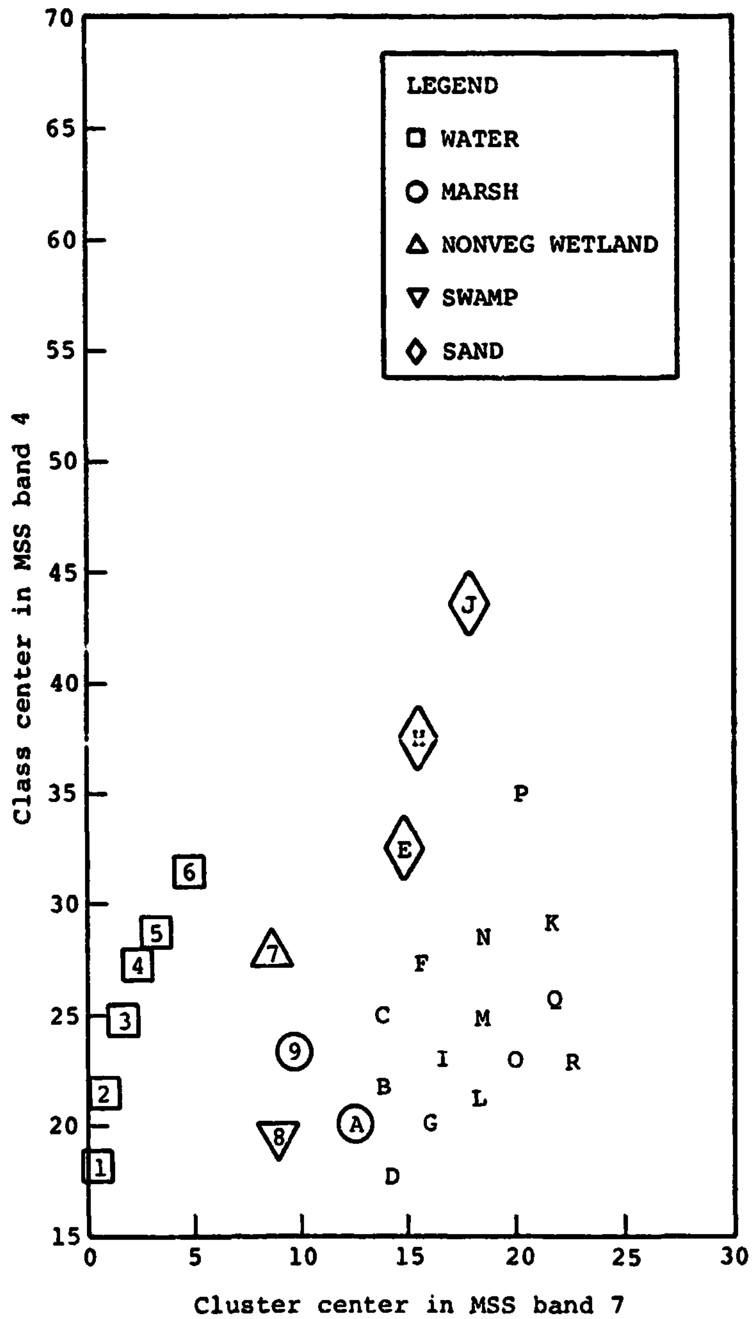


Figure 8-8. - Cluster diagram of Trinity Study Site imagery acquired November 26, 1972.

TABLE 8-X.- CLUSTER IDENTITIES FOR GALVESTON STUDY SITE (IMAGERY ACQUIRED AUGUST 29, 1972)

Cluster Symbol	Cluster Identity
1	Dry grassland
2	High marsh
3	Sand, urban (bright)
4	Water
5	High marsh
6	Sand, urban (bright)
7	Low marsh
8	High marsh
9	Fallout due to bad scan li
A	Dry grassland
B	Urban (residential)
C	Low marsh
D	Urban (residential)
E	Concrete, sand
F	Fallout due to bad scan line
G	Dry grassland
H	Urban (residential)
I	Nonvegetated wetland
J	Water
K	Urban (bright), sand
L	Urban (residential)
M	Concrete, sand
N	Nonvegetated wetland
O	Mixed concrete and vegetation
P	Fallout due to bad scan line

TABLE 8-XI.- CLUSTER MEANS FOR GALVESTON STUDY SITE
(AUGUST 29, 197[illegible] IMAGERY)

Cluster Symbol	Cluster Means*							
	MSS4		MSS5		MSS6		MSS7	
1	37.53	(9.18)	31.06	(8.12)	47.45	(17.28)	24.62	(24.39)
2	31.11	(6.40)	25.35	(5.86)	24.92	(7.75)	10.17	(9.09)
3	49.15	(14.21)	48.00	(14.81)	34.40	(15.99)	18.74	(18.17)
4	37.27	(9.07)	26.87	(6.46)	14.53	(3.36)	3.05	(1.55)
5	34.28	(7.77)	27.95	(6.89)	37.52	(13.08)	18.91	(18.35)
6	71.06	(23.7)	76.23	(25.96)	68.38	(26.13)	29.02	(29.05)
7	29.91	(5.88)	21.68	(4.41)	18.73	(5.13)	6.55	(5.26)
8	33.64	(7.5)	27.39	(6.67)	31.16	(10.39)	14.72	(13.91)
9	36.17	(8.59)	90.19	(31.48)	43.27	(15.51)	22.80	(22.47)
A	33.85	(7.59)	25.02	(5.8)	49.29	(18.06)	26.74	(26.64)
B	46.49	(13.06)	44.26	(13.33)	50.98	(18.77)	24.13	(23.87)
C	33.72	(7.53)	24.84	(5.66)	18.63	(5.09)	5.43	(4.07)
D	39.00	(9.82)	33.99	(9.28)	40.82	(14.48)	19.47	(18.94)
E	56.33	(17.32)	57.79	(18.68)	55.8[illegible]	(20.84)	24.51	(24.28)
F	36.34	(8.67)	79.09	(27.09)	16.41	(4.15)	3.42	(1.94)
G	33.40	(7.39)	25.73	(6.01)	43.04	(15.42)	22.94	(22.61)
H	42.93	(11.52)	40.37	(11.8)	43.25	(15.5)	19.75	(19.24)
I	41.54	(10.92)	38.38	(11.01)	35.64	(12.29)	15.16	(14.37)
J	31.34	(6.5)	19.85	(3.69)	11.32	(2.00)	2.78	(1.26)
K	61.79	(19.69)	64.19	(21.21)	60.31	(22.72)	26.01	(25.86)
L	42.00	(11.12)	37.67	(10.73)	50.60	(18.61)	25.17	(24.98)
M	54.58	(16.56)	54.67	(17.44)	49.47	(18.14)	20.99	(20.55)
N	40.93	(10.65)	35.28	(9.79)	26.71	(8.51)	8.74	(7.58)
O	50.60	(14.84)	50.00	(15.6)	55.50	(20.69)	26.06	(25.92)
P	33.11	(7.27)	58.49	(18.95)	13.7[illegible]	(3.01)	2.89	(1.38)

*The numbers in parentheses represent reflectances (%).

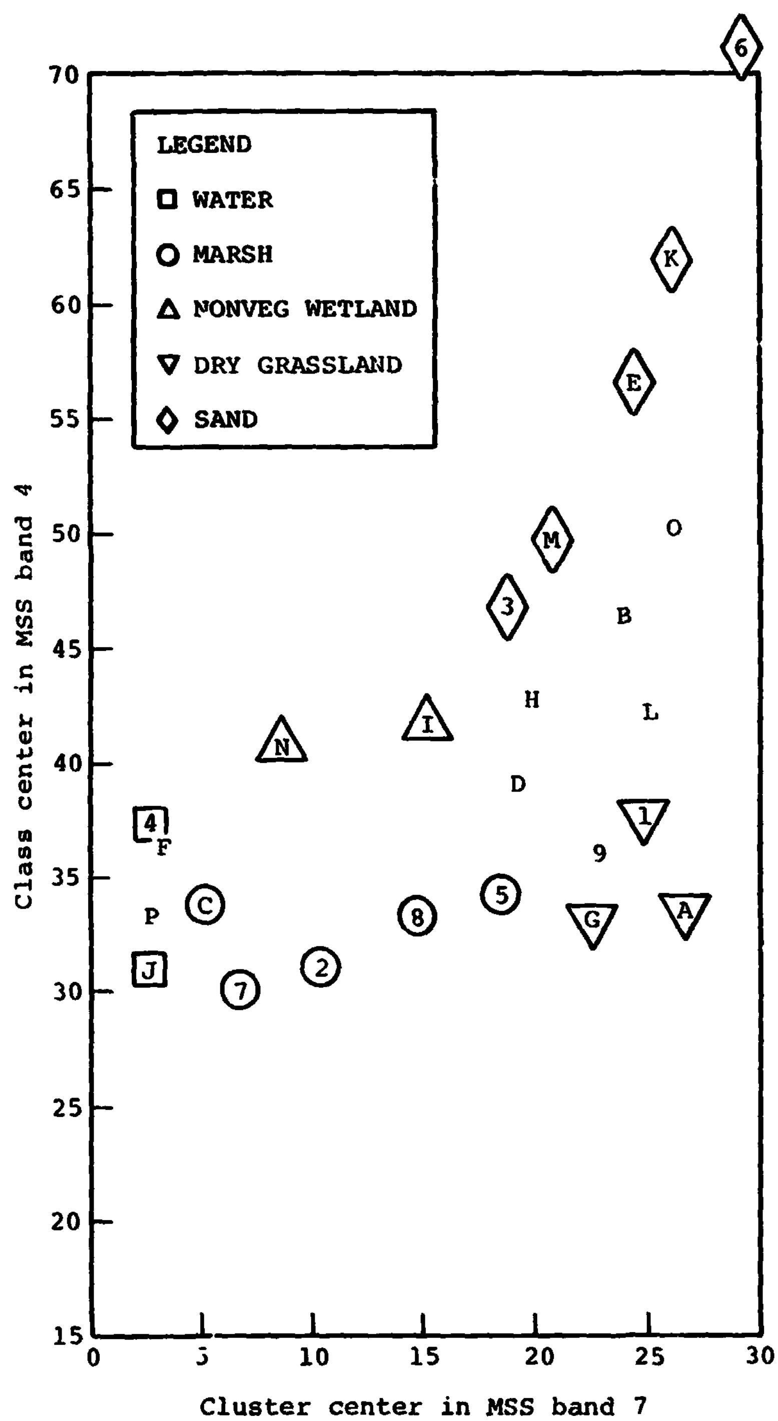


Figure 8-9.- ISOCLS cluster diagram of Galveston Study Site. (Imagery acquired August 29, 1972.)

TABLE 8-XII.- CLUSTER IDENTITIES FOR GALVESTON STUDY SITE (IMAGERY ACQUIRED OCTOBER 3, 1972)

Cluster Symbol	Cluster Identity
1	Sand, urban (bright), concrete
2	Nonvegetated wetland
3	Dry grassland
4	Low marsh
5	Urban (residential)
6	Water
7	Dry grassland
8	Water
9	Urban (bright), concrete, bare soil
A	Nonvegetated wetland
B	Dry grassland
C	Water
D	Urban (residential)
E	Water
F	High marsh
G	Water
H	Sand, concrete
I	High marsh
J	Dry grassland
K	Marsh
L	Urban (residential)
M	Water
N	Dry grassland
O	Sand
P	Marsh

TABLE 8-XIII.- CLUSTER MEANS FOR GALVESTON STUDY SITE
(IMAGERY ACQUIRED OCTOBER 3, 1972)

Cluster Symbol	Cluster Means*							
	MSS4		MSS5		MSS6		MSS7	
1	69.74	(27.46)	74.36	(29.42)	67.56	(29.94)	28.43	(32.7)
2	37.89	(11.86)	32.71	(10.8)	29.13	(11.49)	11.60	(12.54)
3	34.88	(10.38)	26.94	(8.22)	48.73	(20.9)	26.07	(29.87)
4	26.92	(6.48)	18.09	(4.27)	19.38	(6.81)	7.68	(7.84)
5	42.59	(14.16)	37.62	(13.0)	48.91	(20.99)	23.79	(27.14)
6	35.04	(10.46)	25.05	(7.38)	13.11	(3.8)	2.16	(1.23)
7	33.85	(9.88)	26.99	(8.24)	39.53	(22.95)	20.25	(22.9)
8	27.71	(6.87)	14.93	(2.85)	7.38	(1.05)	1.11	(0.00)
9	49.15	(17.37	48.26	(17.75)	49.33	(21.19)	21.89	(24.86)
A	33.58	(9.74)	25.93	(7.77)	21.54	(7.85)	7.65	(7.8)
B	32.66	(9.29)	25.07	(7.39)	44.66	(18.95)	23.85	(27.21)
C	27.09	(6.56)	15.97	(3.32)	9.53	(2.08)	1.32	(0.22)
D	39.39	(12.59)	34.42	(11.57)	39.62	(16.53)	18.36	(20.64)
E	30.07	(8.02)	18.55	(4.47)	9.51	(2.07)	1.30	(0.2)
F	30.96	(8.46)	23.93	(6.88)	32.[illegible]1	(13.07)	16.34	(18.22)
G	24.27	(5.18)	12.63	(1.83)	7.01	(0.87)	1.14	(0.01)
H	56.97	(21.21)	58.36	(22.27)	54.00	(23.43)	22.90	(26.07)
I	28.73	(7.37)	21.10	(5.61)	25.76	(9.87)	11.81	(12.79)
J	30.61	(8.29)	22.09	(6.05)	47.27	(20.2)	26.01	(29.8)
K	25.77	(5.92)	16.09	(3.37)	13.45	(3.97)	3.98	(3.41)
L	38.43	(12.12)	31.70	(10.35)	48.67	(20.87)	24.92	(28.49)
M	31.93	(8.94)	21.06	(5.59)	11.19	(2.88)	1.81	(0.81)
N	29.91	(7.95)	22.11	(6.06)	39.87	(16.65)	21.41	(24.29)
O	46.09	(15.87)	44.51	(16.08)	40.97	(17.18)	16.98	(18.98)
P	28.66	(7.33)	19.87	(5.06)	14.59	(4.51)	4.28	(3.77)

*The numbers in parentheses represent reflectances (%).

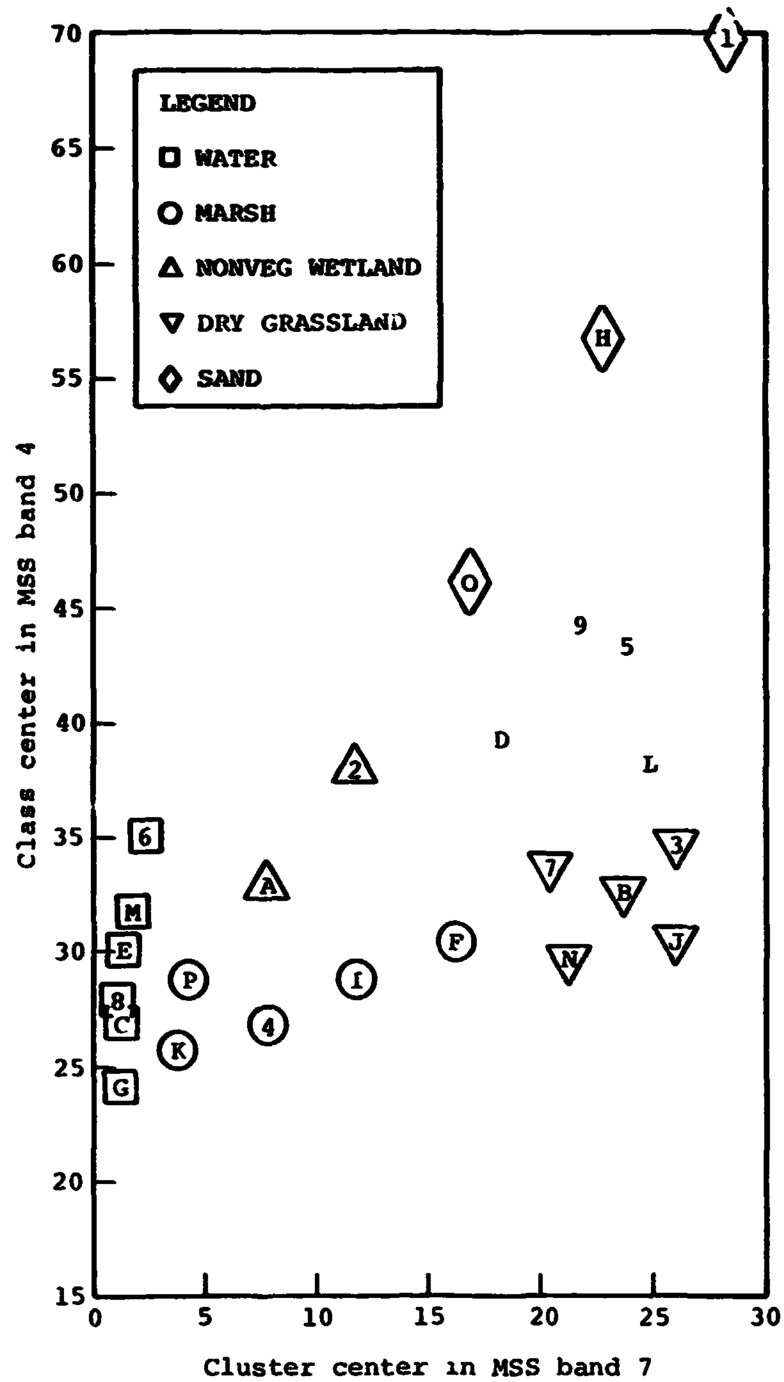


Figure 8-10.- Cluster diagram of Galveston Study Site of imagery acquired October 3, 1972.

TABLE 8-XIV.- CLUSTER IDENTITIES FOR GALVESTON STUDY SITE OF NOVEMBER 26, 1972, IMAGERY

Cluster Symbol	Cluster Identity
1	Urban (bright)
2	Water
3	Sand
4	Marsh
5	Urban (residential)
6	Water
7	Dry grassland
8	Water
9	Urban (residential)
A	Water
B	Nonvegetated wetland
C	Water
D	Dry grassland
E	High marsh
F	Urban (residential)
G	Water
H	Dry grassland
I	Dry grassland
J	Urban (residential)
K	Marsh
L	Dry grassland
M	Marsh
N	Sand, concrete
O	Urban (residential)
P	Dry grassland
Q	Dry grassland
R	Nonvegetated wetland
S	Concrete
T	Urban (residential)
U	Marsh

TABLE 8-XV.- CLUSTER MEANS, GALVESTON STUDY SITE
NOVEMBER 26, 1972

Cluster Symbol	Cluster Means*							
	MSS4		MSS5		MSS6		MSS7	
1	51.46	(27.12)	52.38	(27.67)	48.69	(28.83)	21.45	(33.40)
2	27.72	(11.57)	21.12	(8.91)	10.76	(4.52)	1.39	(1.08)
3	33.30	(15.22)	30.59	(14.59)	26.42	(14.56)	10.74	(16.14)
4	19.82	(6.39)	13.45	(4.31)	11.48	(4.98)	3.60	(4.64)
5	27.24	(11.25)	21.85	(9.35)	40.59	(23.64)	23.45	(36.62)
6	25.73	(10.26)	13.61	(4.41)	5.03	(0.84)	0.35	(0.00)
7	21.29	(7.35)	16.43	(6.1)	24.45	(13.29)	13.90	(21.23)
8	19.61	(6.25)	10.56	(2.58)	4.57	(0.55)	0.36	(0.00)
9	31.30	(13.91)	27.33	(12.64)	39.12	(22.7)	20.86	(32.45)
A	26.89	(11.02)	16.43	(6.1)	6.78	(1.97)	0.52	(0.00)
B	31.21	(13.85)	27.19	(12.55)	19.39	(10.05)	5.42	(7.57)
C	21.23	(7.32)	12.78	(3.91)	5.85	(1.37)	.49	(0.00)
D	24.65	(9.56)	20.95	(8.81)	28.63	(15.97)	16.32	(25.13)
E	20.24	(6.67)	14.53	(4.96)	19.45	(10.09)	10.24	(15.34)
F	37.12	(17.72)	35.30	(17.42)	37.66	(21.76)	17.96	(27.77)
G	26.10	(10.51)	17.99	(7.03)	9.08	(3.44)	1.12	(0.64)
H	25.39	(10.04)	21.25	(8.99)	24.63	(13.41)	12.59	(19.12)
I	24.63	(9.54)	19.92	(8.19)	32.16	(18.23)	-8.98	(31.03)
J	32.80	(14.89)	31.16	(14.94)	31.79	(18.0)	15.10	(23.17)
K	24.76	(9.63)	19.99	(8.23)	20.38	(10.68)	9.46	(14.08)
L	22.30	(8.02)	17.80	(6.92)	28.75	(16.05)	16.93	(26.11)
M	20.13	(6.6)	14.06	(4.68)	15.17	(7.34)	6.82	(9.83)
N	42.24	(21.08)	42.07	(21.48)	38.96	(22.59)	17.12	(26.42)
O	28.61	(12.15)	26.04	(11.86)	25.69	(14.09)	11.78	(17.82)
P	26.44	(10.73)	21.29	(9.01)	35.41	(20.32)	20.52	(31.9)
Q	30.32	(13.27)	26.53	(12.16)	34.62	(18.81)	18.63	(28.85)
R	27.62	(11.5)	23.56	(10.38)	19.03	(9.82)	6.79	(9.78)
S	37.32	(17.85)	35.11	(17.31)	31.90	(18.07)	14.11	(21.57)
T	28.79	(12.27)	25.76	(11.7)	30.60	(17.23)	15.87	(24.41)
U	24.47	(9.44)	18.67	(7.44)	15.96	(7.85)	5.96	(8.44)

*Numbers in parentheses represent reflectances (%).

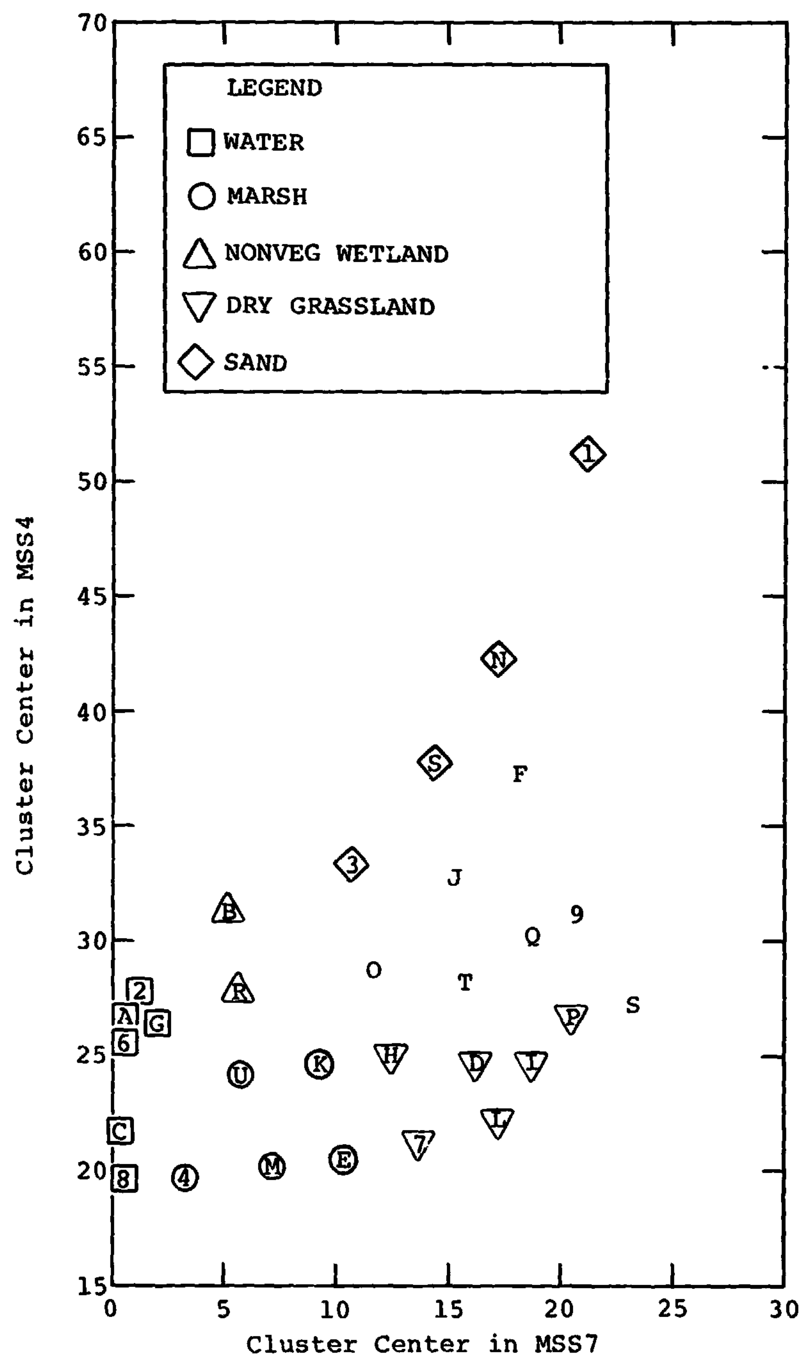


Figure 8-11. - Cluster diagram of data acquired over Galveston Study Site November 26, 1972.

TABLE 8-XVI.- BOLIVAR STUDY SITE CLUSTER IDENTITIES

Cluster Symbol	Cluster Identity
1	Water
2	Water
3	Water
4	Water
5	Nonvegetated wetland
6	Low marsh
7	Marsh
8	Nonvegetated wetland
9	Marsh
A	Sand
B	Marsh
C	[illegible]y grassland
D	Mixture of grass and bare soil
E	Sand
F	Dry grassland
G	Urban (residential)
H	Sand
I	Urban (residential, recreational)
J	Sand
K	Dry grassland
L	Urban (residential)
M	Sand

TABLE 8-XVII.- BOLIVAR STUDY SITE CLUSTER MEANS
(IMAGERY ACQUIRED AUGUST 28, 1972)

Cluster Symbol	Cluster Means*							
	MSS4		MSS5		MSS6		MSS7	
1	27.74	(4.94)	13.36	(1.13)	6.53	(0.0)	1.25	(0.0)
†2	30.09	(5.96)	17.31	(2.69)	7.68	(0.46)	1.50	(0.0)
†3	31.52	(6.58)	19.73	(3.64)	9.68	(1.3)	1.68	(0.1)
4	33.76	(7.55)	23.98	(5.32)	12.62	(2.55)	2.63	(1.11)
5	36.48	(8.73)	30.54	(8.2)	24.69	(7.65)	8.66	(7.49)
6	30.08	(5.95)	22.49	(4.73)	22.28	(6.63)	8.92	(7.77)
7	30.54	(6.15)	23.10	(4.97)	29.77	(9.8)	14.44	(13.61)
8	42.02	(11.12)	38.68	(11.13)	35.22	(12.11)	14.48	(13.65)
9	35.18	(8.16)	29.72	(7.59)	34.03	(11.6)	16.01	(15.27)
A	50.29	(14.71)	48.64	(15.06)	44.47	(16.02)	18.39	(17.8)
B	32.59	(7.04)	25.35	(5.86)	38.95	(13.69)	20.04	(19.54)
C	36.73	(8.83)	31.84	(8.43)	42.13	(15.03)	20.81	(20.36)
D	42.64	(11.39)	40.13	(11.7)	45.32	(16.38)	21.09	(20.65)
E	55.89	(17.13)	55.91	(17.93)	54.08	(20.09)	23.54	(23.25)
F	33.20	(7.31)	25.14	(5.78)	45.71	(16.55)	24.28	(24.03)
G	48.18	(13.79)	45.63	(13.87)	54.37	(20.21)	25.53	(25.36)
H	62.18	(18.85)	63.52	(20.91)	59.15	(22.23)	24.86	(24.65)
I	37.01	(8.96)	30.02	(7.71)	51.10	(18.83)	26.73	(26.63)
J	67.07	(21.97)	71.20	(23.97)	65.24	(24.81)	27.41	(27.35)
K	32.94	(7.19)	23.36	(5.08)	51.49	(18.99)	27.93	(27.9)
L	41.34	(10.83)	35.23	(9.77)	56.15	(20.96)	28.40	(28.4)
M	73.78	(24.88)	79.38	(27.21)	70.47	(27.02)	29.02	(29.05)

*Numbers in parentheses represent reflectance (%).

†Water groups 2 and 3 were chained by ISOCLS.

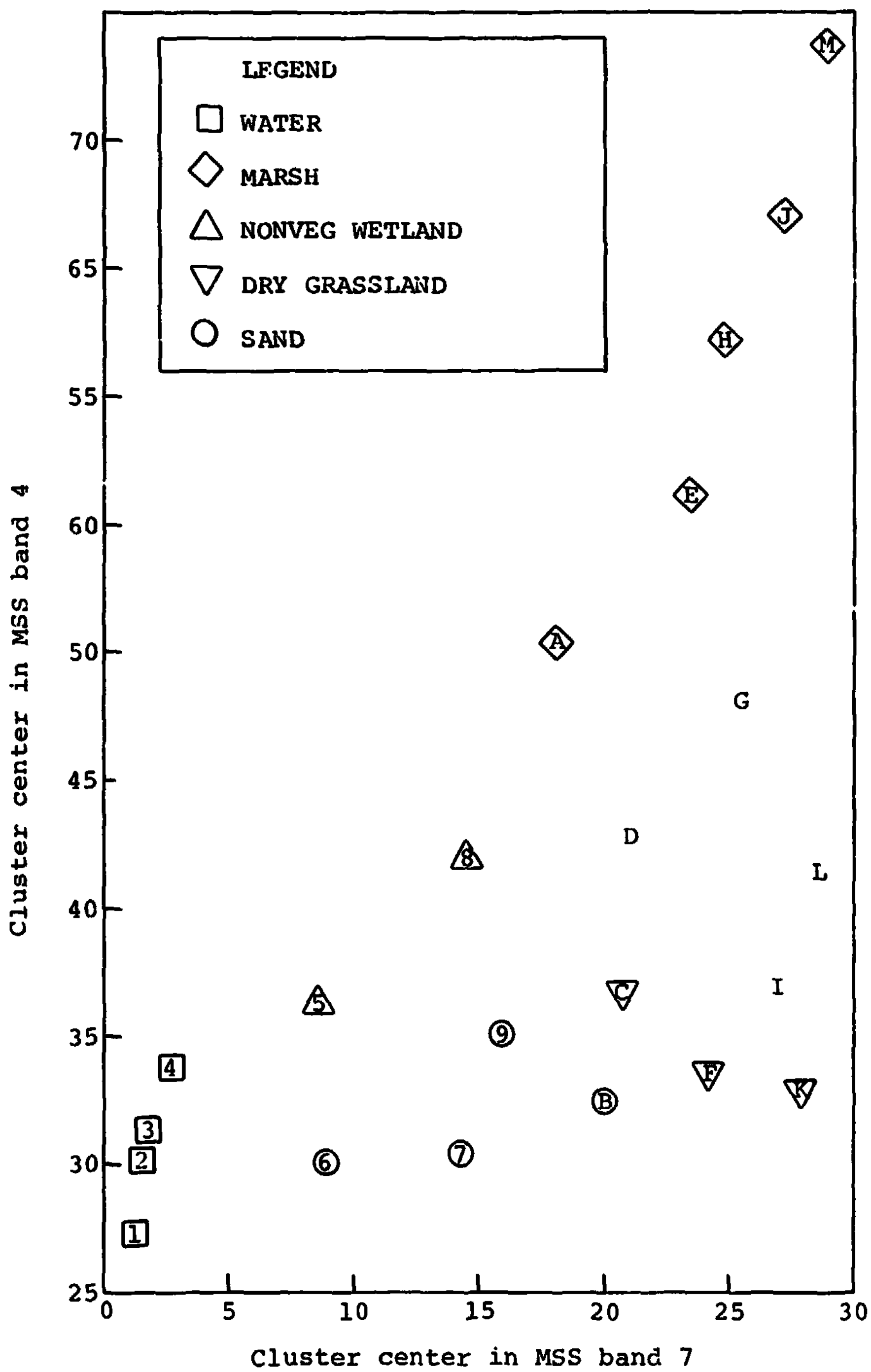


Figure 8-12. - Bolivar Study Site cluster diagram (data acquired August 28, 1972).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-25493

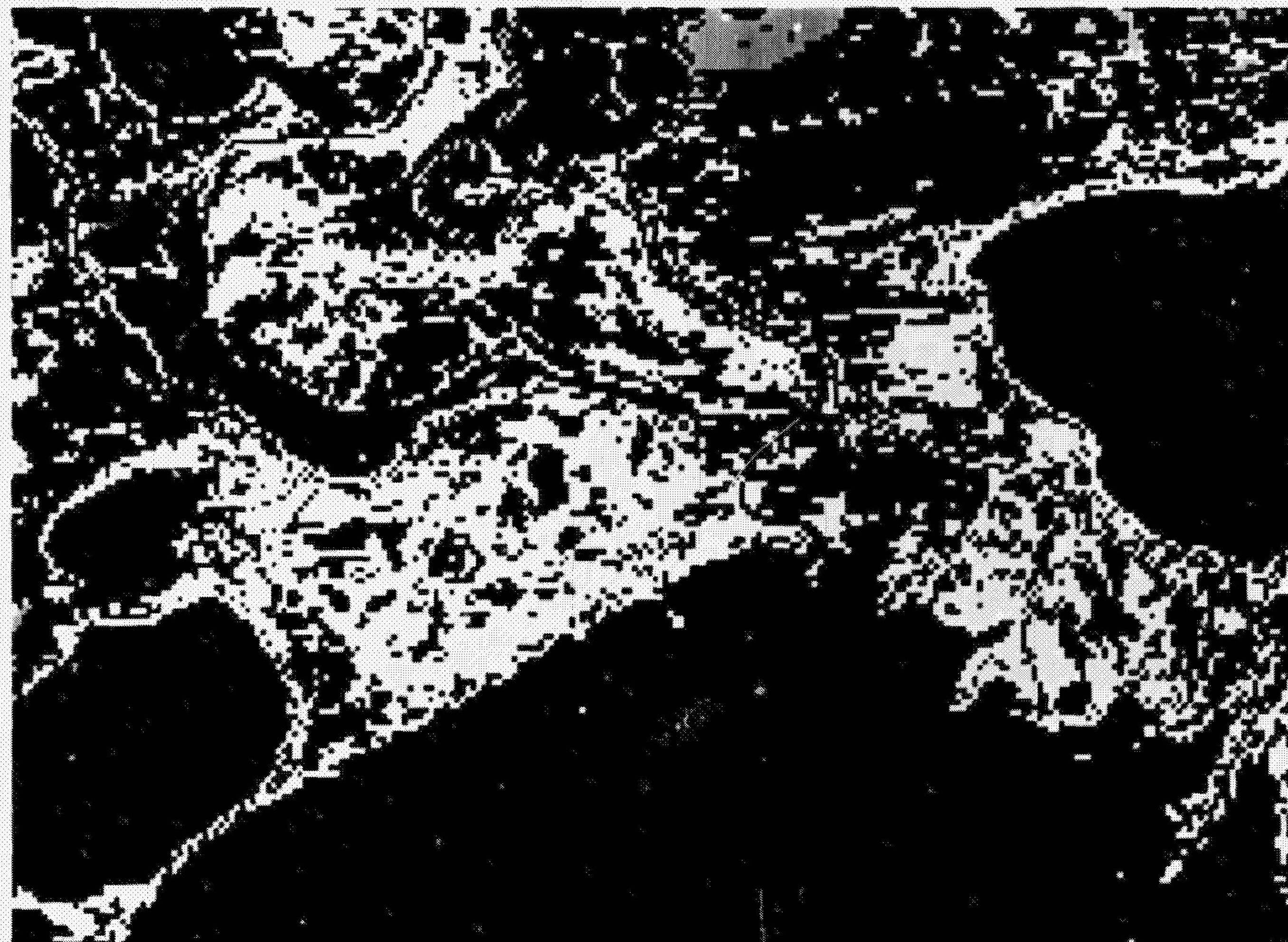


Figure 8-13.- Level II wetland and land and Level I water cluster map of Trinity Study Site (imagery acquired August 29, 1972). See table 8-I, page 8-44 for color code. For cluster identity, see table 8-IV, page 8-22, and figure 8-6, page 8-24.

Table 8-I is repeated here for convenience when referring to figures.

TABLE 8-I.- STANDARD COLOR CODE FOR DIGITAL PROCESSING RESULTS DISPLAY

Level	Study Feature	Color Code
I	• Water	Blue
	• Wetland	Yellow
	• Land	Red
II Water	• Water Masses	Blue-Light Brown
II Wetland	• Swamp	Purple
	• Marsh	Yellow
	• Nonvegetated Wetland	Brown
II Land	• Land, Sand	White
	• Barrier Flat Vegetation, Grassland	Green
	• Other	Black
	• Forest	Red

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-25498

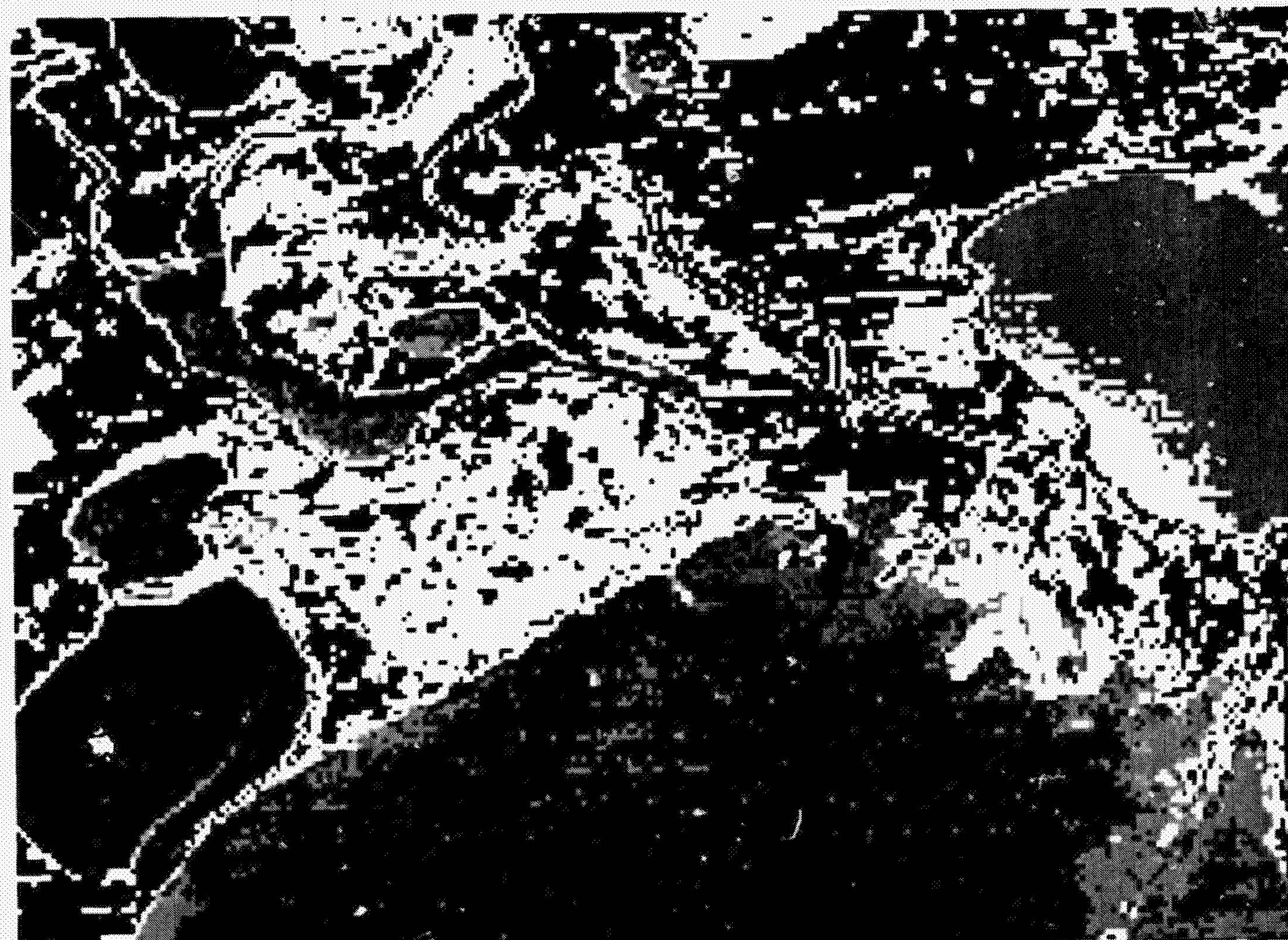


Figure 8-14.- Level II water cluster map of Trinity Study Site (imagery acquired August 29, 1972). See table 8-I, page 8-44, for color code. For cluster identity, see table 8-IV, page 8-22, and figure 8-6, page 8-24.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28095

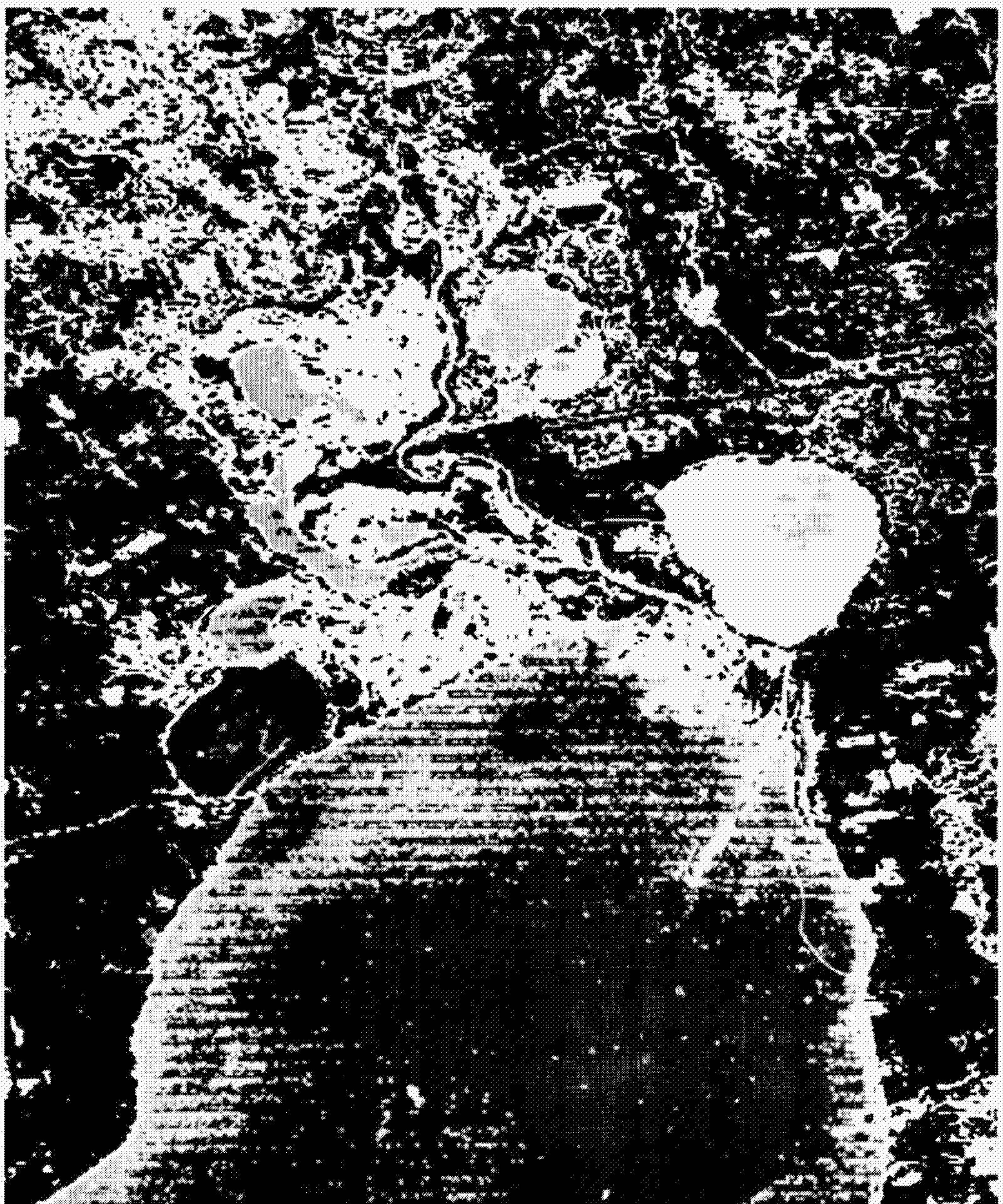
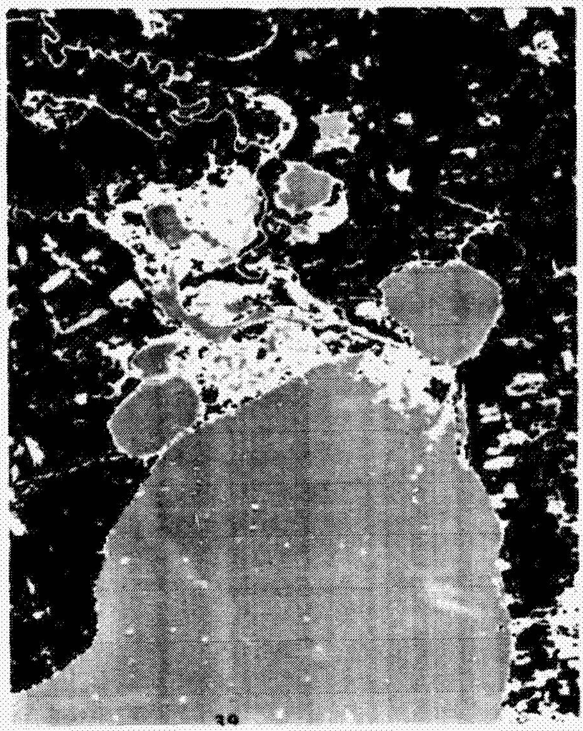


Figure 8-15.- Level II cluster map of Trinity Study Site (imagery acquired October 3, 1972). See table 8-I, page 8-44, for color code. For cluster identity, see table 8-VI, page 8-25, and figure 8-7, page 8-27.

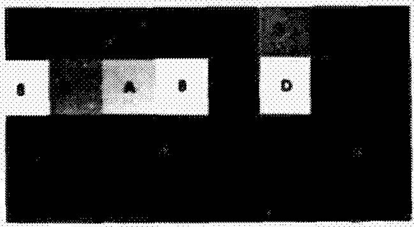
REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28096



Special Level III
Cluster Map

NASA S-73-28137



Color Code

Figure 8-16.- Special Level III wetland cluster map of Trinity Study Site (imagery acquired October 3, 1972). See table 8-VI, page 8-48, for cluster symbols.

Table 8-VI is repeated here for convenience where referring to figures.

TABLE 8-VI.- CLUSTER IDENTITIES, TRINITY STUDY SITE, OCTOBER 3, 1972

Cluster Symbol	Cluster Identity
1	Water
2	Water
3	Water
4	Nonvegetated wetland
5	Marsh
6	Nonvegetated wetland
7	Marsh, rice fields
8	Sand, bare soil
9	Marsh, rice fields
A	Swamp
B	Bare soil
C	Mixed bare soil and vegetation
D	Marsh
E	Dry grassland
F	Pine forest
G	Mixed bare soil and vegetation
H	Dry grassland
I	Deciduous forest
J	Dry grassland
K	Concrete, bare soil, sand
L	Urban (residential)
M	Dry grassland
N	Dry grassland
O	Mixed bare soil and vegetation
P	Mixed concrete and vegetation
Q	Dry grassland
R	Bare soil, concrete
S	Dry grassland
T	Urban (residential)
U	Urban (bright), shell, bare soil
V	Dry grassland
W	Urban (residential)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28121

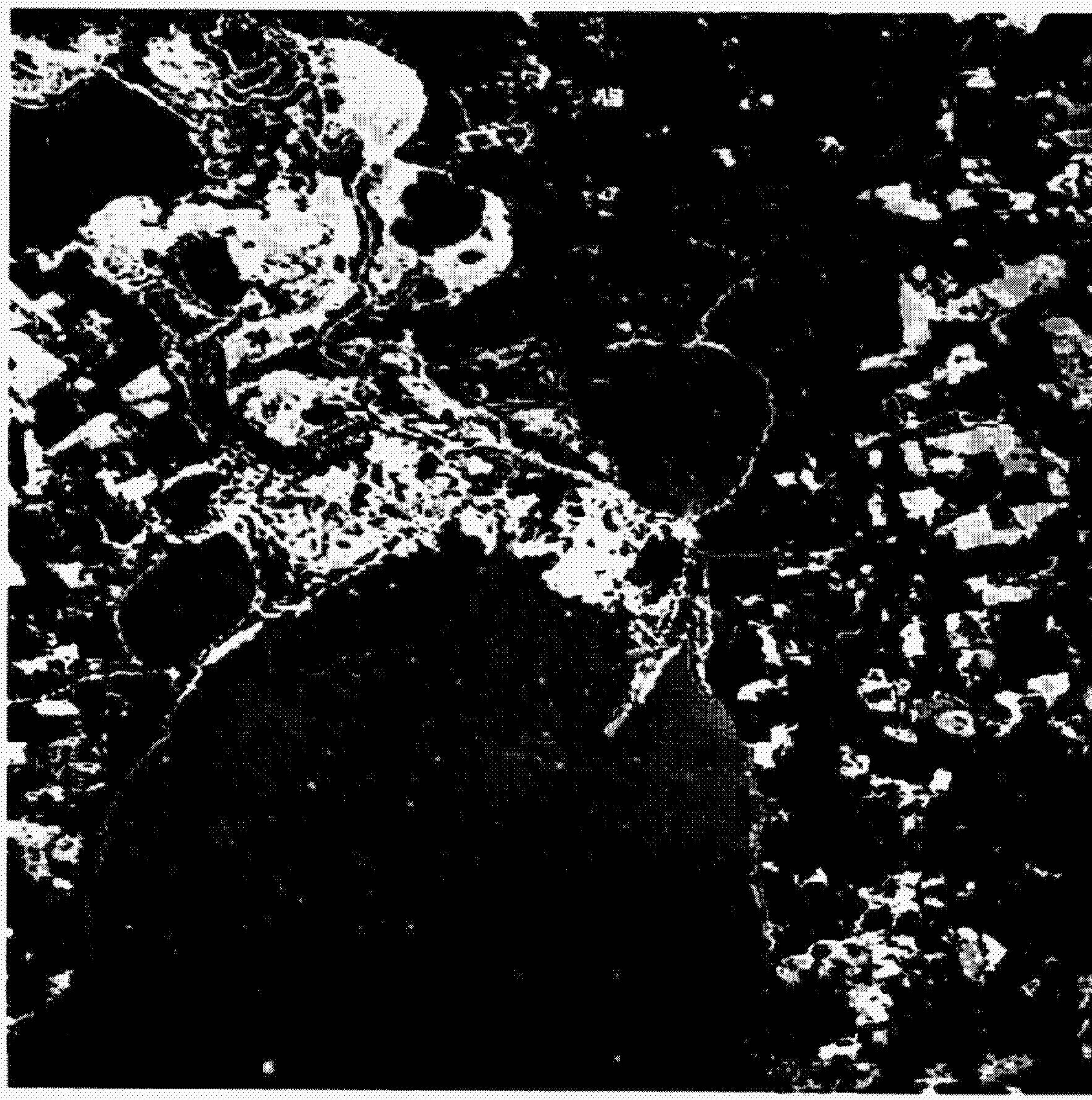


Figure 8-17.- Level II wetland and land cluster map of Trinity Study Site (imagery acquired November 26, 1972). For cluster identity see table 8-VIII, page 8-28, and figure 8-8, page 8-30.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28158

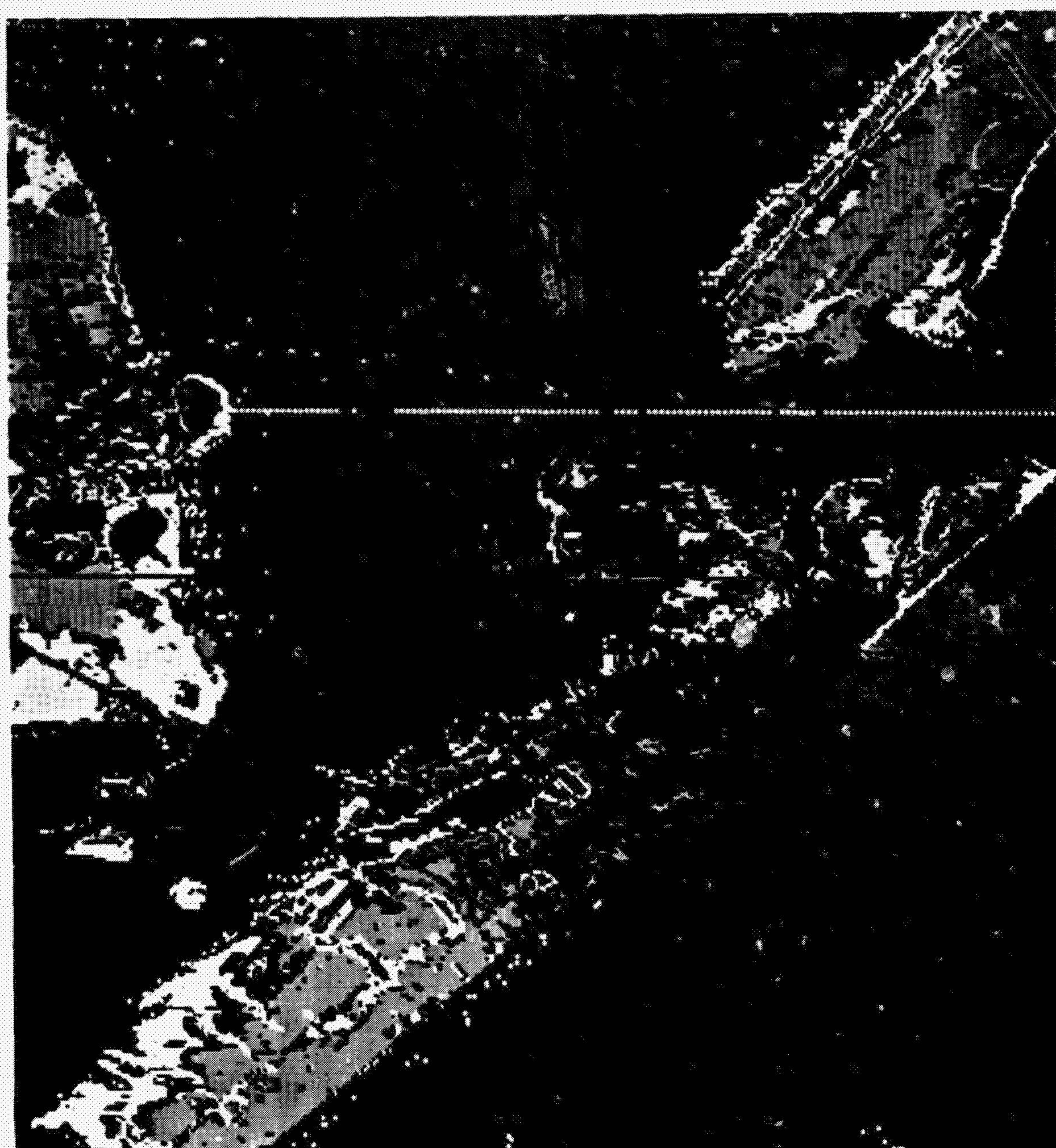


Figure 8-18.- Level II land and wetland and Level I water cluster map of Galveston Study Site (imagery acquired August 29, 1972). See table 8-I, page 8-44, for color code. For cluster identity, see table 8-X, page 8-31, and figure 8-9, page 8-33.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28157

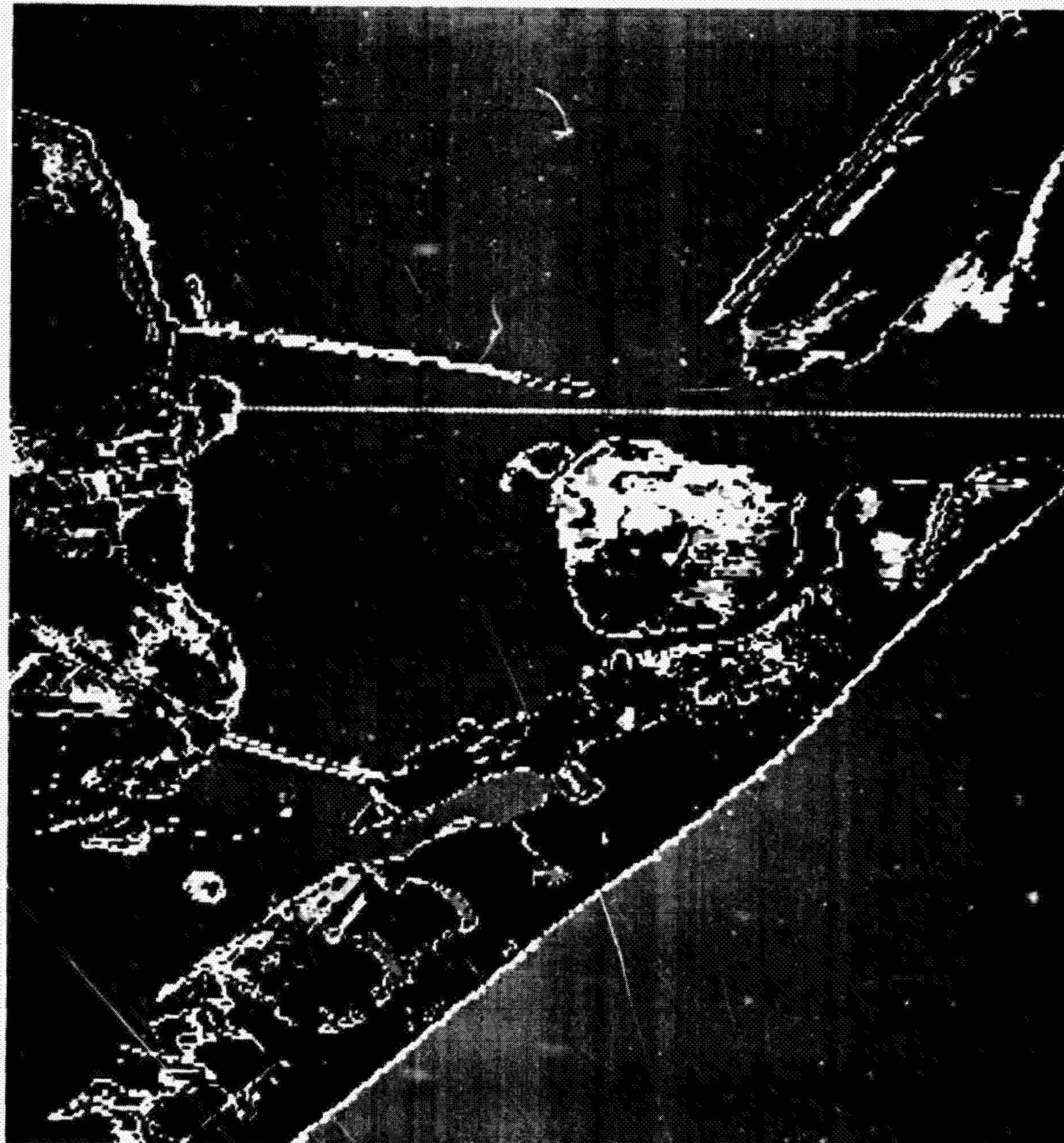


Figure 8-19.- Level III wetland cluster map of Galveston Study Site (imagery acquired August 29, 1972). See table 8-X, page 8-31, and figure 8-9, page 8-33, for cluster identity.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28167

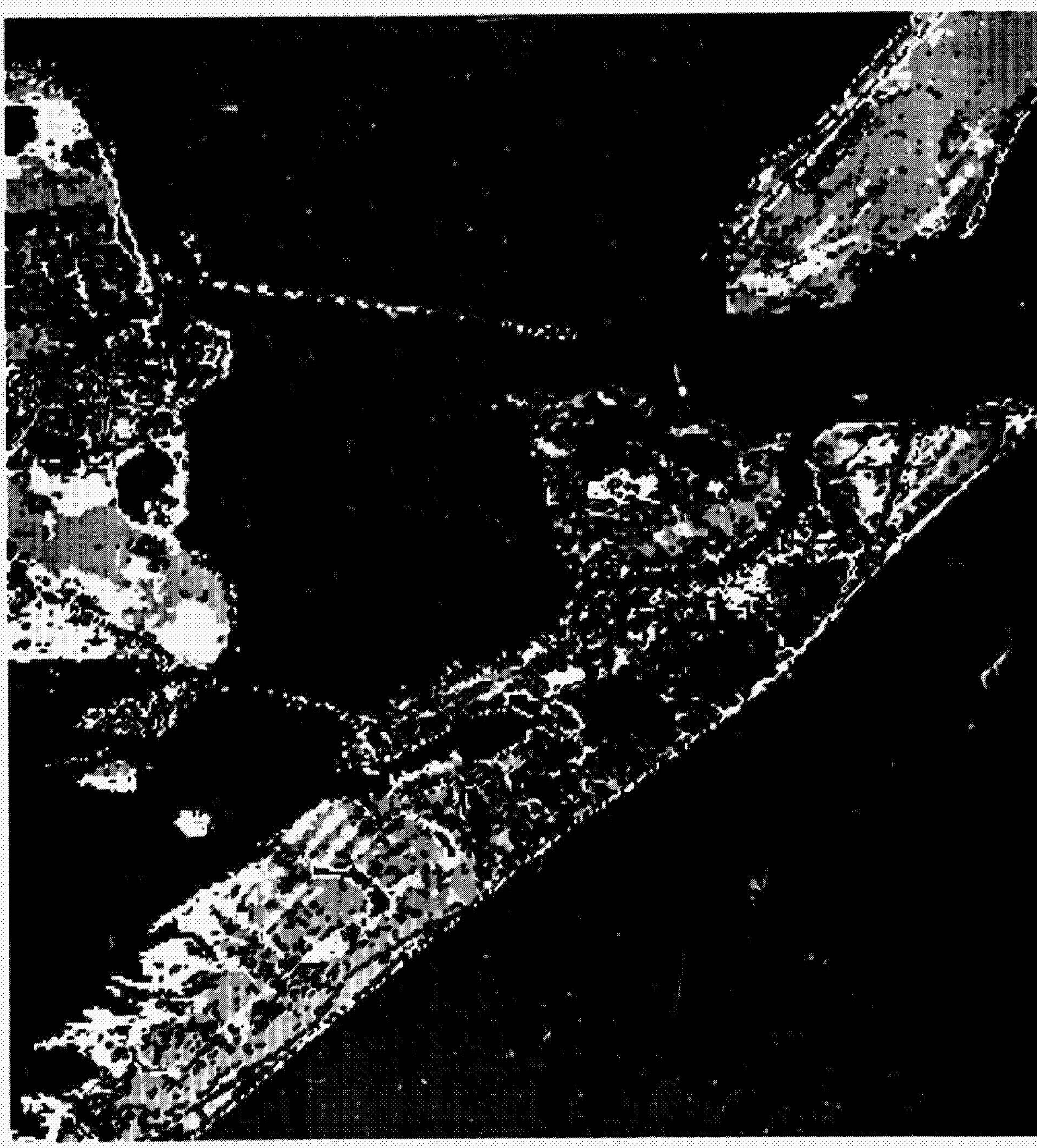


Figure 8-20.- Level II wetland and land cluster map of Galveston Study Site (imagery acquired October 3, 1972). See table 8-I, page 8-44, for color code. For cluster identity, see table 8-XII, page 8-34, and figure 8-10, page 8-36.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28155

Figure 8-21.- Level III wetland cluster map of Galveston Study Site (imagery acquired October 3, 1972). See table 8-XII, page 8-34, and figure 8-10, page 8-36, for cluster identity.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28154

Figure 8-22.- Level III land cluster map of Galveston Study Site (imagery acquired November 26, 1972). See table 8-XIV, page 8-37, and figure 8-11, page 8-39 for cluster identity.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28075

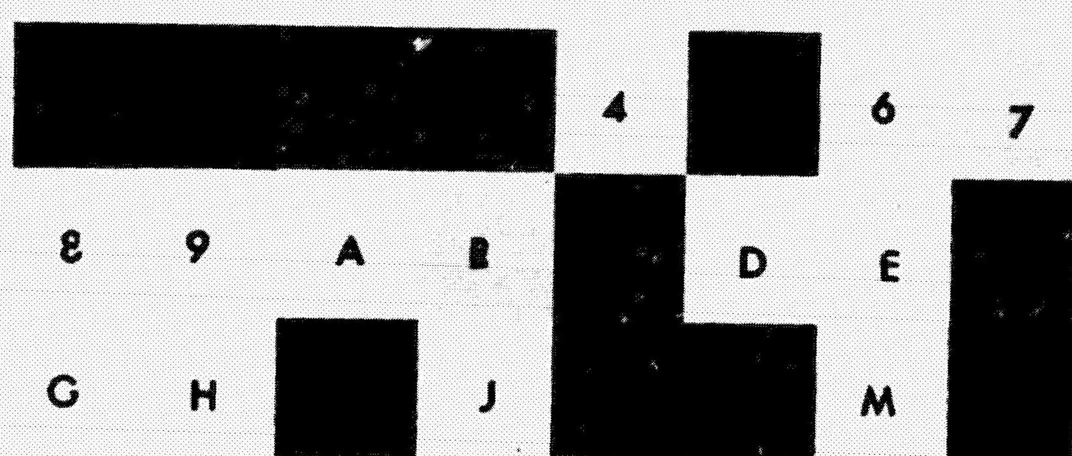


Figure 8-23a.- Color code for Level II Bolivar Study Site land cluster map. See table 8-XVI, page 8-48 for cluster symbol identities.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28079

Figure 8-23b.- Level II land cluster map of Bolivar Study Site (imagery acquired August 28, 1972). See figure 8-23a, page 8-53, for color code. For cluster identity, see table 8-XVI, page 8-40, and figure 8-12, page 8-42.

The class means for the LARSYS analyses are given in tables 8-XVIII through 8-XXI; the associated class diagrams are given in figures 8-24 through 8-27. Examples of the classification maps produced by the LARSYS maximum likelihood classification algorithm and the DAS are given in figures 8-28 through 8-33. Other class maps are given in appendix B.

TABLE 8-XVIII.- CLASS MEANS FOR TRINITY STUDY SITE OF OCTOBER 3, 1972, IMAGERY

Class Symbol	Type Field	Class Means[a]			
		MSS4	MSS5	MSS6	MSS7
1	Water 1	20.96 (4.88)	12.17 (2.63)	6.95 (1.63)	1.05 (0.42)
2	Water 2	30.87 (9.59)	24.97 (8.21)	13.83 (4.87)	2.01 (1.56)
3	Water 3	28.09 (8.27)	22.33 (7.06)	12.65 (4.32)	1.84 (1.36)
4	Water 4	25.85 (7.2)	15.19 (3.94)	8.80 (2.5)	1.13 (0.51)
5	Water 5	25.07 (6.33)	14.09 (3.46)	7.77 (2.02)	1.04 (0.41)
6	Water 6	27.13 (7.81)	16.14 (4.36)	9.01 (2.6)	1.11 (0.49)
7	Marsh 1	29.25 (8.82)	20.02 (6.05)	41.94 (18.11)	20.32 (23.31)
8	Urban	34.10 (11.13)	26.90 (9.05)	47.09 (20.54)	25.52 (29.49)
9	Marsh 2	26.63 (7.58)	18.25 (5.28)	27.53 (11.33)	13.51 (15.22)
A	Water 7	26.36 (7.45)	18.91 (5.56)	17.88 (6.79)	5.90 (6.18)
B	Marsh 4	25.20 (8.8)	20.95 (6.45)	45.38 (19.73)	25.92 (29.96)
C	Hardwood 1	24.99 (6.8)	15.42 (4.04)	35.41 (15.04)	19.65 (22.51)
D	Levee	26.44 (7.49)	17.94 (5.14)	41.44 (17.88)	24.19 (27.91)
E	Hardwood 2	24.51 (6.57)	14.89 (3.81)	34.05 (14.4)	19.60 (22.45)
F	Pine	23.16 (5.92)	13.47 (3.19)	30.83 (12.88)	18.05 (20.61)
G	Marsh 5	26.54 (7.53)	19.49 (5.82)	25.96 (10.59)	13.29 (14.96)
H	Grass	27.55 (8.01)	19.60 (5.87)	41.73 (18.01)	23.65 (27.27)
I	Marsh 6	24.27 (6.45)	15.48 (4.07)	17.00 (6.37)	6.68 (7.11)

[a]The numbers in parentheses represent reflectances (%).

[b]A training field was defined for marsh, but the class fell primarily within the water area.

[c]A training field was defined to represent swamp, but this class fell primarily with deciduous forest.

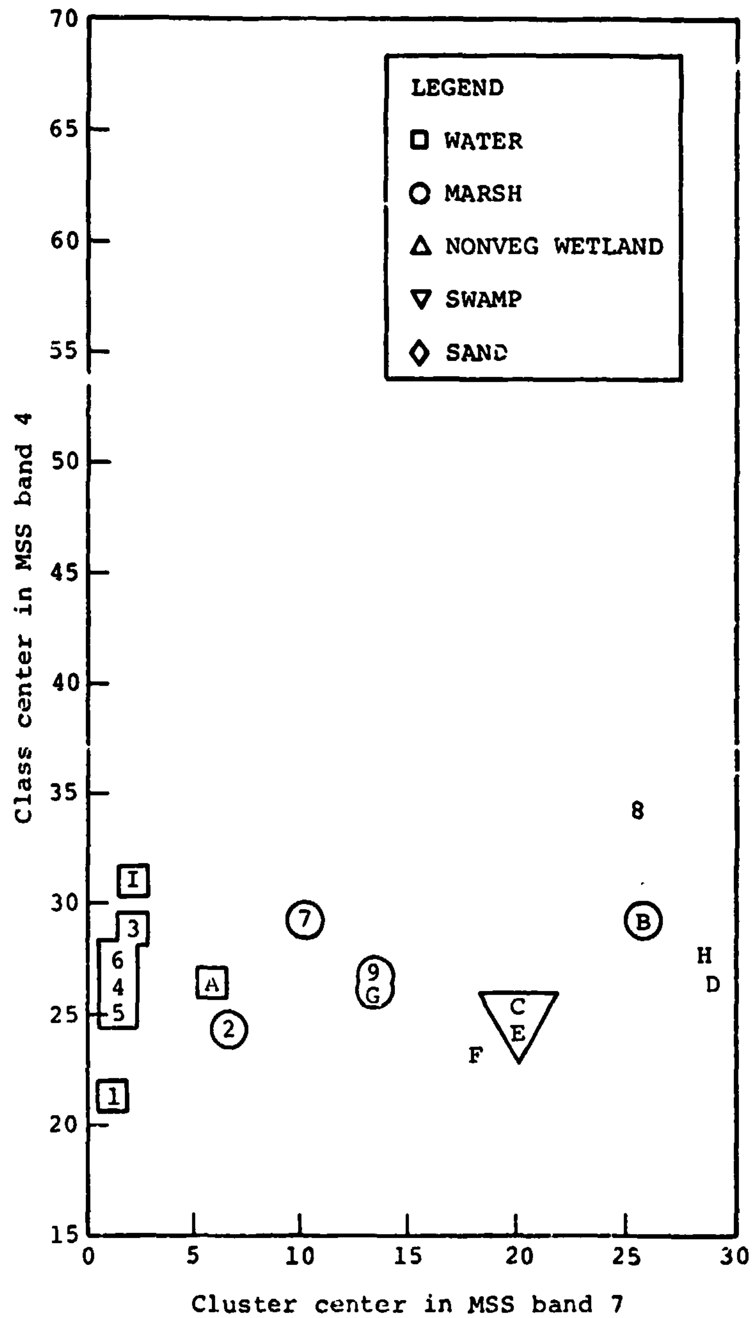


Figure 8-24.- Class diagram for Trinity Study Site of imagery acquired October 3, 1972.

TABLE 8-XIX.- CLASS MEANS FOR TRINITY STUDY SITE OF NOVEMBER 26, 1972, IMAGE Y

Class Symbol	Type Field	Class Means[a]			
		MSS4	MSS5	MSS6	MSS7
1	Water 1	17.31 (5.53)	9.89 (2.81)	4.90 (1.27)	0.46 (0.00)
2	Water 2	25.11 (10.55)	20.10 (8.83)	11.48 (5.46)	1.44 (1.43)
3	Water 3	25.62 (10.87)	19.86 (8.69)	10.72 (4.98)	1.22 (1.08)
4	Water 4	21.67 (8.33)	14.11 (5.29)	7.24 (2.76)	0.60 (0.09)
5	Water 5	31.09 (14.39)	31.52 (15.57)	22.33 (12.37)	4.02 (5.56)
6	Water 6	27.81 (12.28)	25.86 (12.23)	16.25 (8.5)	2.34 (2.87)
7	Marsh 1	23.91 (9.77)	19.7[illegible] (8.6)	19.78 (10.75)	9.04 (13.59)
8	Marsh 2	25.04 (10.5)	20.65 (9.15)	19.68 (10.69)	7.93 (11.82)
9	Marsh 3[b]	20.52 (7.59)	16.14 (6.49)	25.31 (14.27)	15.03 (23.18)
A	Marsh 5	19.98 (7.25)	14.70 (5.64)	22.14 (12.25)	12.89 (17.75)
B	Swamp	19.41 (6.88)	13.92 (5.18)	18.78 (10.11)	10.10 (15.29)
C	Sand	28.22 (12.55)	25.17 (11.82)	25.94 (14.67)	12.22 (18.68)
D	Levee	21.77 (8.4)	17.44 (7.26)	27.64 (15.76)	16.56 (25.82)
E	Marsh 4	23.17 (9.3)	20.31 (8.95)	24.36 (13.67)	12.90 (19.77)
F	Marsh 6	20.34 (7.48)	14.83 (5.72)	21.49 (11.84)	12.46 (19.07)
G	Pine	17.40 (5.59)	10.44 (3.13)	21.78 (12.02)	13.31 (20.43)

[a]The numbers in parentheses represent reflectances (%).

[b]Dry marsh or grassland.

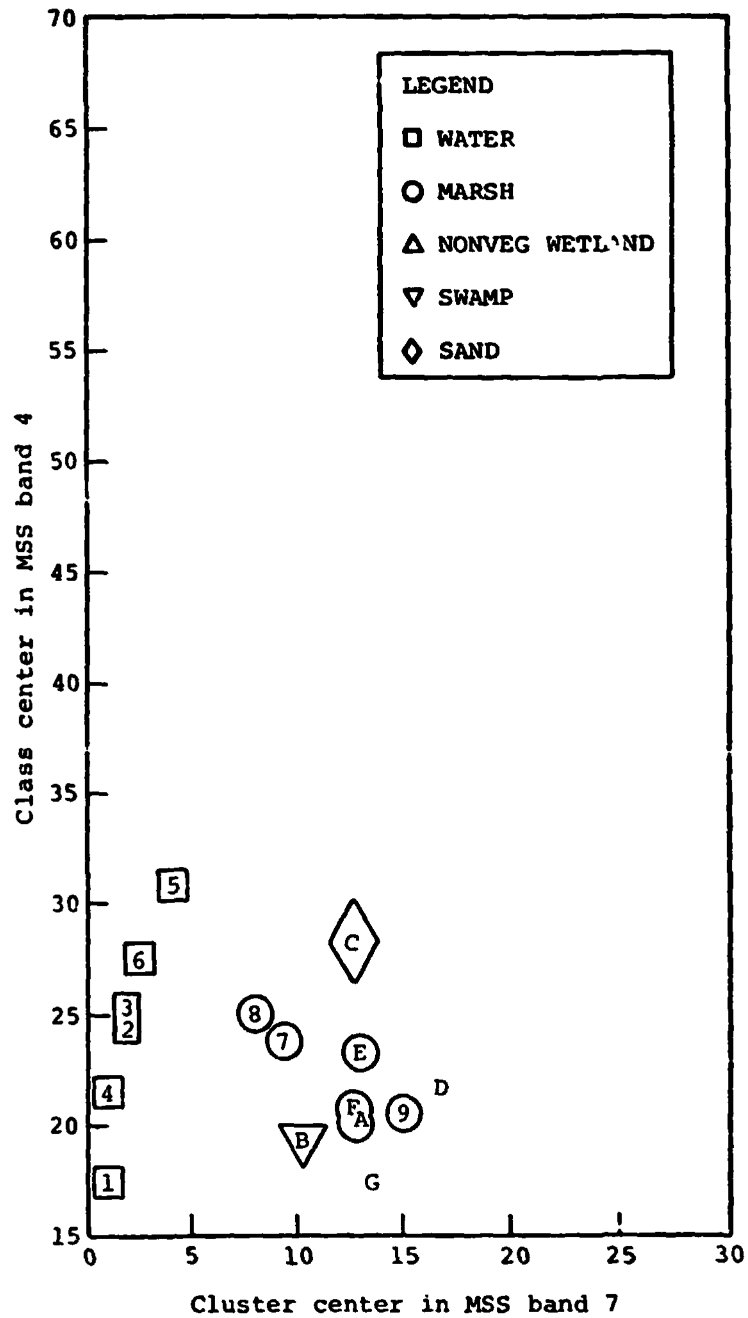


Figure 8-25. - Class diagram of Trinity Study Site (imagery acquired November 26, 1972).

TABLE 8-XX.- CLASS MEANS FOR GALVESTON STUDY SITE OF OCTOBER 3, 1972, DATA

Class Symbol	Type Field	Class Means* MSS4	MSS5	MSS6	MSS7
1	Beach	50.48 (18.03)	50.99 (18.97)	44.22 (18.74)	18.54 (20.85)
2	Marsh 1	25.92 (5.99)	16.65 (3.62)	13.52 (4.0)	3.85 (3.25)
3	Marsh 2	25.67 (5.87)	16.91 (3.74)	16.62 (5.49)	5.83 (5.62)
4	Marsh 3	25.95 (6.01)	16.78 (3.68)	17.72 (6.02)	6.82 (6.81)
5	Tidal Flat	34.74 (10.31)	29.33 (9.29)	26.00 (9.99)	10.51 (11.23)
6	Urban 1	47.17 (16.4)	48.02 (17.64)	45.15 (18.18)	18.94 (21.33)
7	Urban 2	38.83 (12.32)	33.35 (11.09)	39.75 (16.59)	18.64 (20.97)
8	Barrier Flat Veg.	33.88 (9.89)	26.36 (7.96)	44.73 (18.98)	23.77 (27.12)
9	Marsh 4	25.11 (5.59)	16.20 (3.42)	17.00 (5.67)	6.52 (6.45)
A	Spoil	40.47 (13.12)	35.92 (12.24)	38.45 (15.97)	17.30 (19.37)
B	Main. Veg.	30.13 (8.05)	23.35 (6.62)	45.72 (19.46)	24.86 (28.42)
C	Water 6	34.42 (10.16)	25.63 (7.64)	12.97 (3.74)	1.97 (1.0)
D	Water 5	31.45 (8.7)	20.55 (5.37)	10.57 (2.58)	1.40 (0.32)
E	Water 3	26.77 (6.41)	14.25 (2.55)	6.93 (0.84)	0.95 (0.00)
F	Water 2	23.65 (4.88)	12.43 (1.74)	7.08 (0.91)	1.20 (0.08)
G	Water 4	30.32 (8.15)	15.49 (3.1)	7.86 (1.28)	1.29 (0.19)
H	Water 7	35.31 (10.59)	25.55 (7.6)	12.54 (3.53)	1.87 (0.88)
I	Water 1	21.07 (3.61)	10.03 (0.66)	5.35 (0.08)	0.86 (0.00)

*Numbers in parentheses represent reflectances (%).

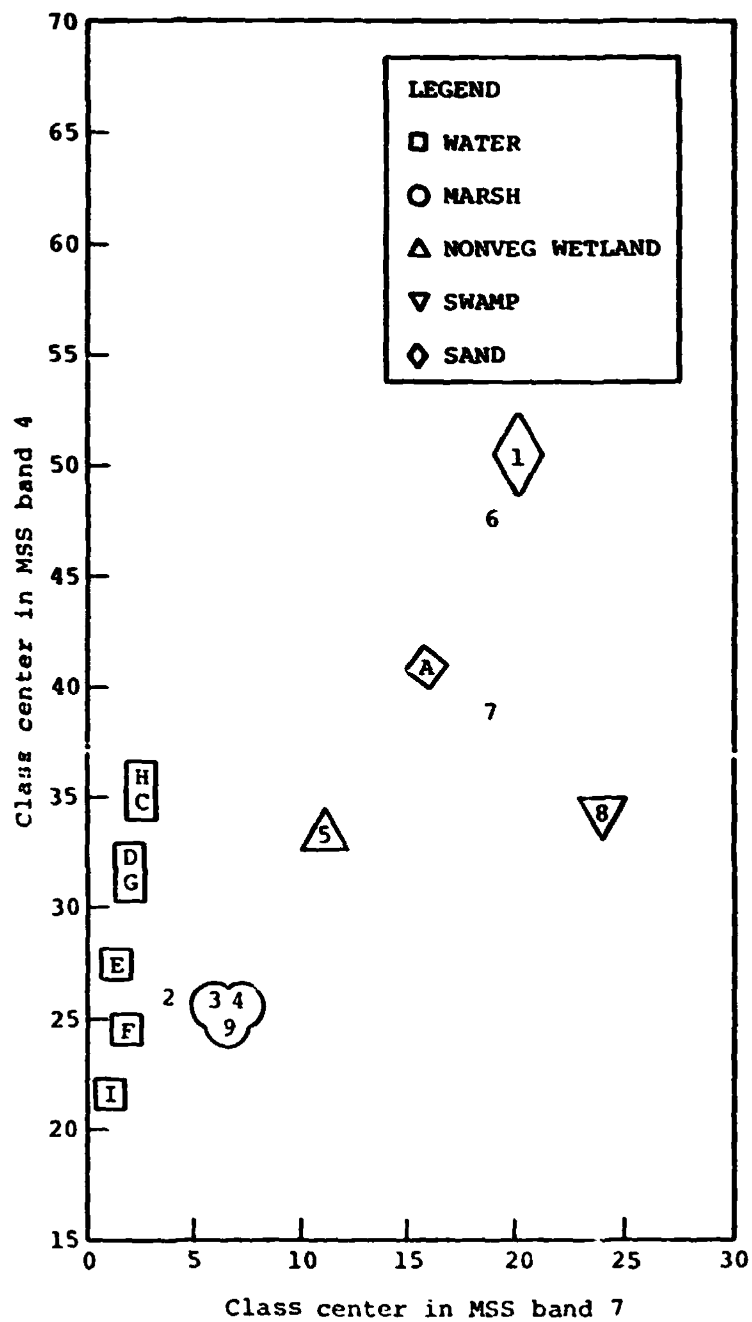


Figure 8-26. - Class diagram of Galveston Study Site (imagery acquired October 3, 1972).

TABLE 8-XXI.- CLASS MEANS OF GALVESTON STUDY SITE FOR NOVEMBER 26, 1972, DATA

Class Symbol	Type Field	Class Means*			
		MSS4	MSS5	MSS6	MSS7
1	Marsh 1	23.04 (8.5)	16.73 (6.28)	14.08 (6.65)	4.90 (6.73)
2	Marsh 2	21.67 (7.6)	15.59 (5.59)	14.67 (7.02)	5.61 (7.88)
3	Tidal Flat	26.89 (11.02)	23.65 (10.43)	21.34 (11.3)	9.18 (13.63)
4	Marsh 3	20.71 (6.98)	14.43 (4.9)	14.55 (6.95)	5.90 (8.34)
5	Marsh 4	20.14 (6.6)	13.98 (4.63)	13.68 (6.39)	4.78 (6.54)
6	Marsh 5	19.10 (5.92)	12.67 (3.84)	11.26 (4.84)	3.33 (4.2)
7	Water 1	26.08 (10.49)	13.47 (4.32)	4.84 (0.72)	0.33 (0.00)
8	Water 2	19.27 (6.03)	10.07 (2.28)	4.27 (0.36)	0.32 (0.00)
9	Water 3	21.60 (7.56)	13.72 (4.47)	5.90 (1.4)	0.47 (0.00)
A	Water 4	27.25 (11.26)	16.59 (6.19)	6.74 (1.94)	0.42 (0.00)
B	Water 5	27.71 (11.56)	21.00 (8.84)	10.27 (4.2)	1.29 (0.92)
C	Sand	34.25 (15.84)	31.11 (14.91)	27.14 (15.02)	12.19 (18.48)
D	Vegetation	24.44 (9.42)	20.12 (8.31)	30.99 (17.48)	18.21 (28.18)
E	Urban 1	28.73 (12.23)	24.15 (10.73)	28.59 (15.95)	14.49 (22.18)
F	Urban 2	34.62 (16.09)	32.71 (15.87)	34.44 (17.7)	16.54 (25.49)
G	Vegetation	22.92 (8.42)	20.12 (8.31)	27.65 (15.34)	16.06 (24.71)

*The numbers in parentheses are reflectances (%).

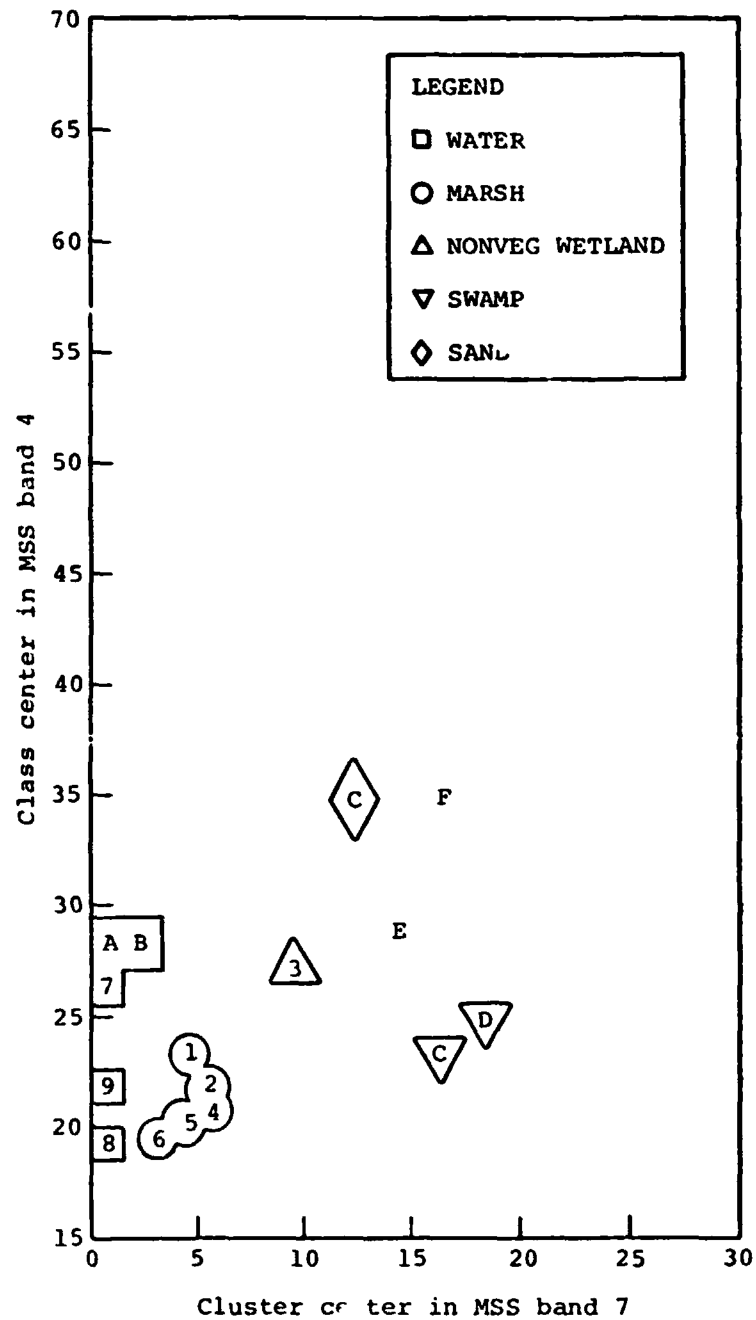


Figure 8-27. - Class diagram of Galveston Study Site (imagery acquired November 26, 1972).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28118

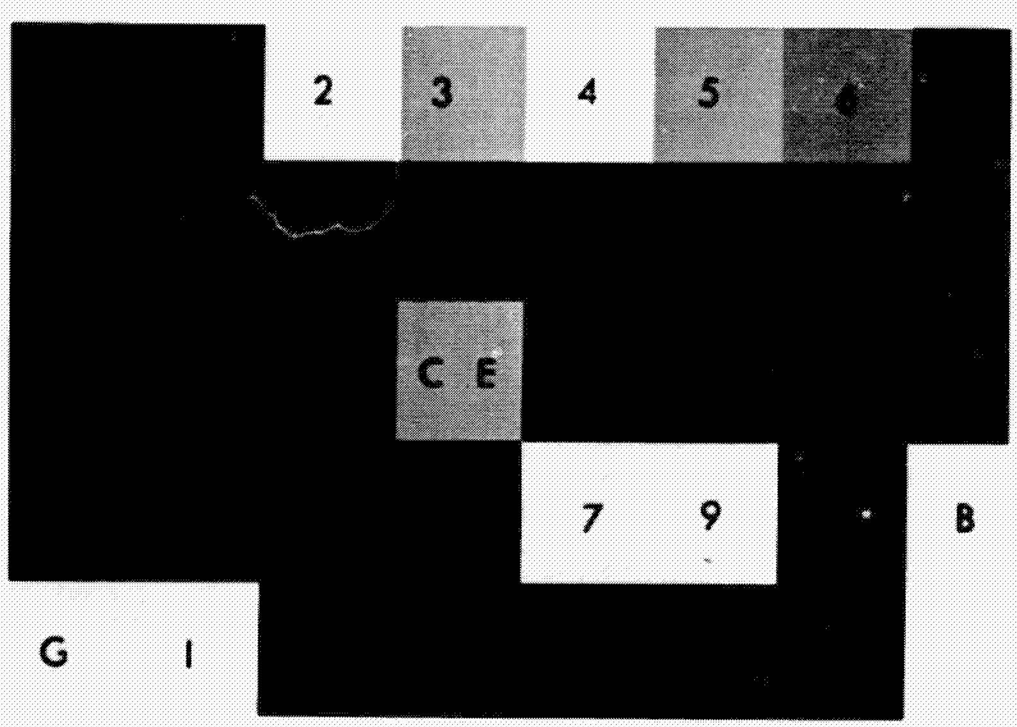


Figure 8-28a.- Color code of Level II class map of Trinity Study Site. See table 8-XVIII, page 8-58, for class symbols and means.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28087

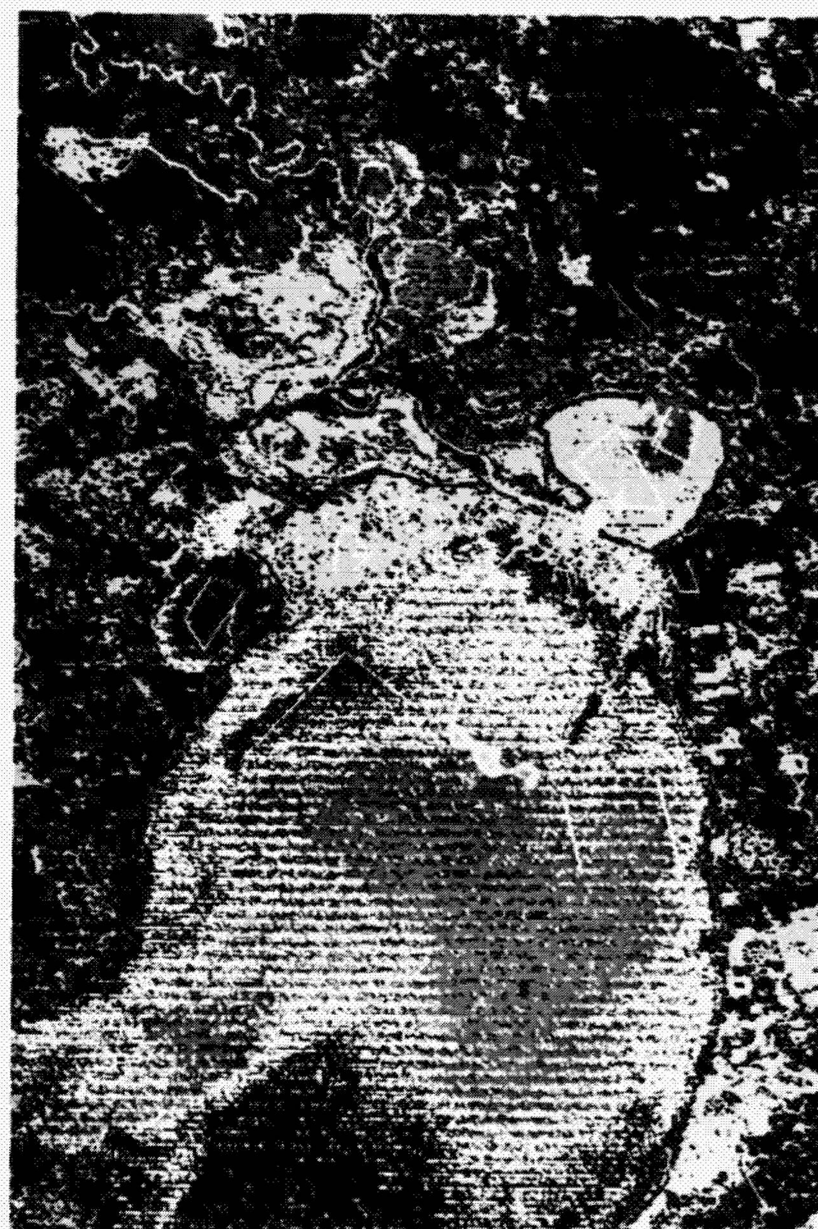


Figure 8-28b.- Level II class map of Trinity Study Site (imagery acquired October 3, 1972). For class symbols, means and diagram, see figure 8-28a, page 8-66, table 8-XVIII, page 8-58, and figure 8-24, page 8-59.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28135 NASA S-73-28136

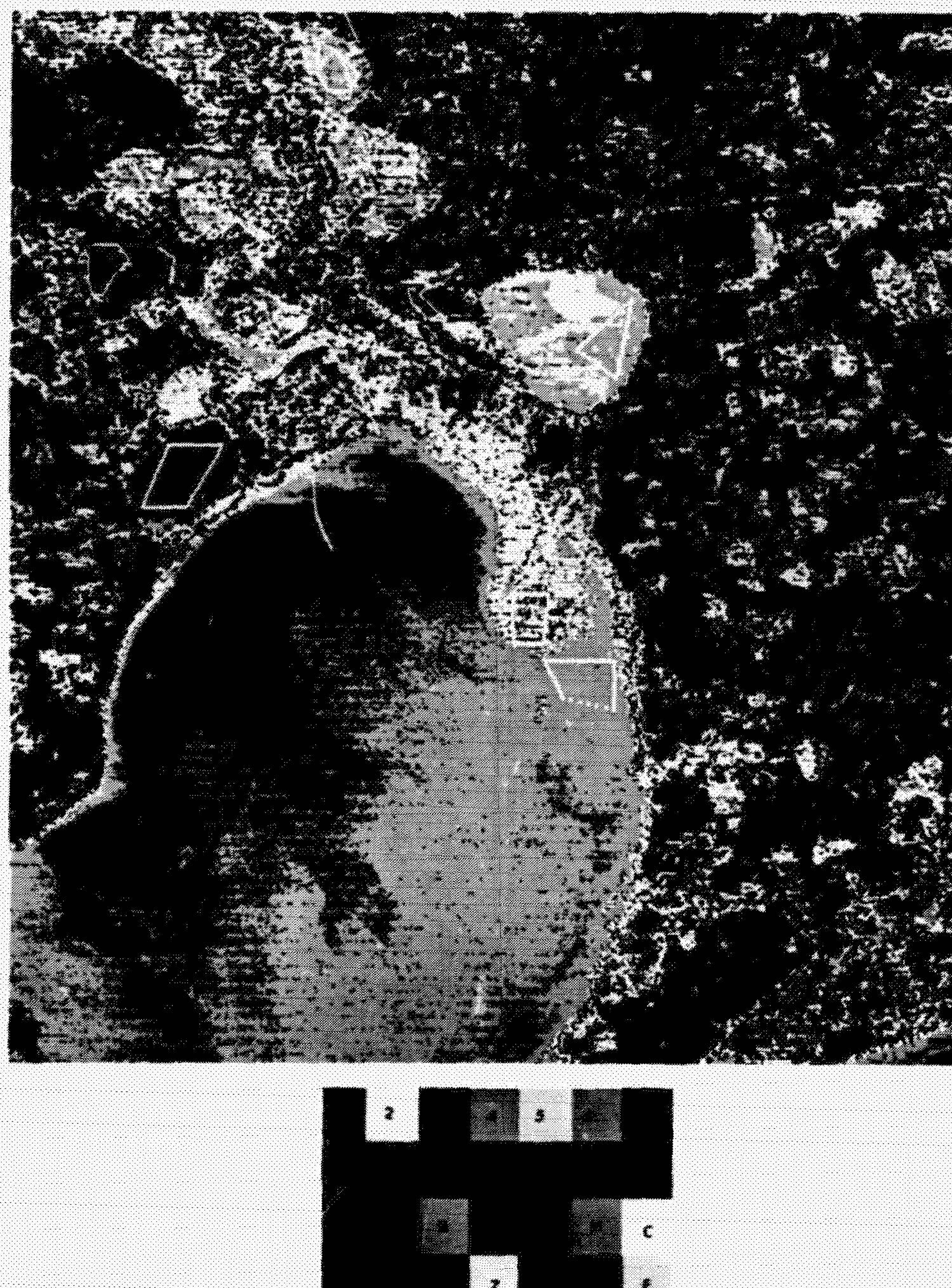


Figure 8-29.- Level II class map of Trinity Study Site (imagery acquired November 26, 1972). For class symbols, means and diagram, see table 8-XIX, page 8-60, table 8-I, page 8-44, and figure 8-25, page 8-61.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28179

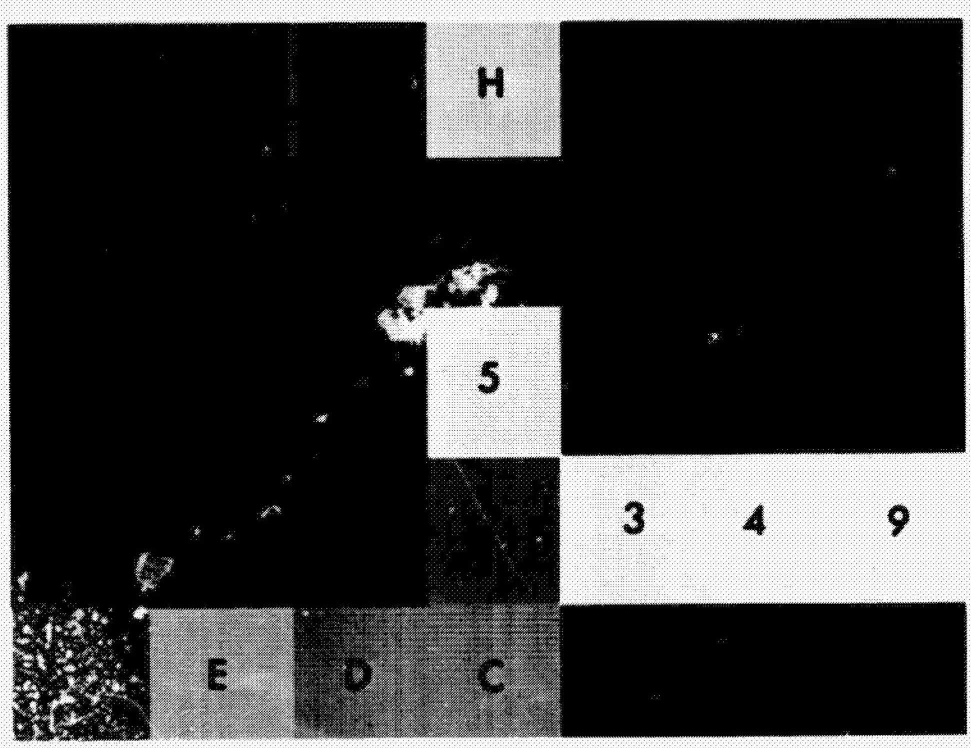


Figure 8-30a.- Color code for Level II water class map of Galveston Study Site. For class symbols and means, see table 8-XX, page 8-62.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28170

Figure 8-30b.- Level II water class map of Galveston Study Site (analysis 2 of imagery acquired October 3, 1972. For color code, class means and diagram, see figure 8-30a, page 8-71, table 8-XX, page 8-64; and figure 8-26, page 8-65.)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28175

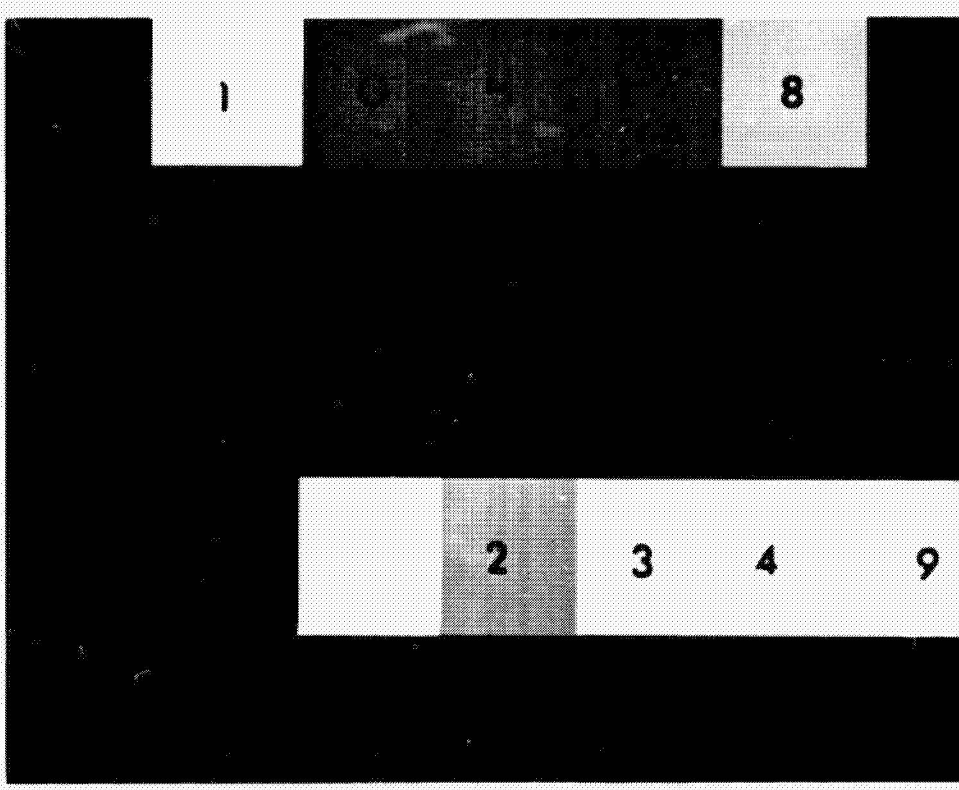


Figure 8-31a.- Color code of Level II wetland and land class map of Galveston Study Site. For class symbols, means and diagram, see table 8-XX, page 8-62, and figure 8-26, page 8-63.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28183

Figure 8-31b.- Level II wetland and class map of Galveston Study Site (analysis 2 of imagery acquired October 3, 1972). See figure 8-31a, page 8-71, for color code.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28150

Figure 8-32.- Level II wetland and land class map of Galveston Study Site (imagery acquired November 26, 1972). For color code, class means and diagram, see table 8-I, page 8-46, table 8-XXI, page 8-64, and figure 8-27, page 8-65.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28171

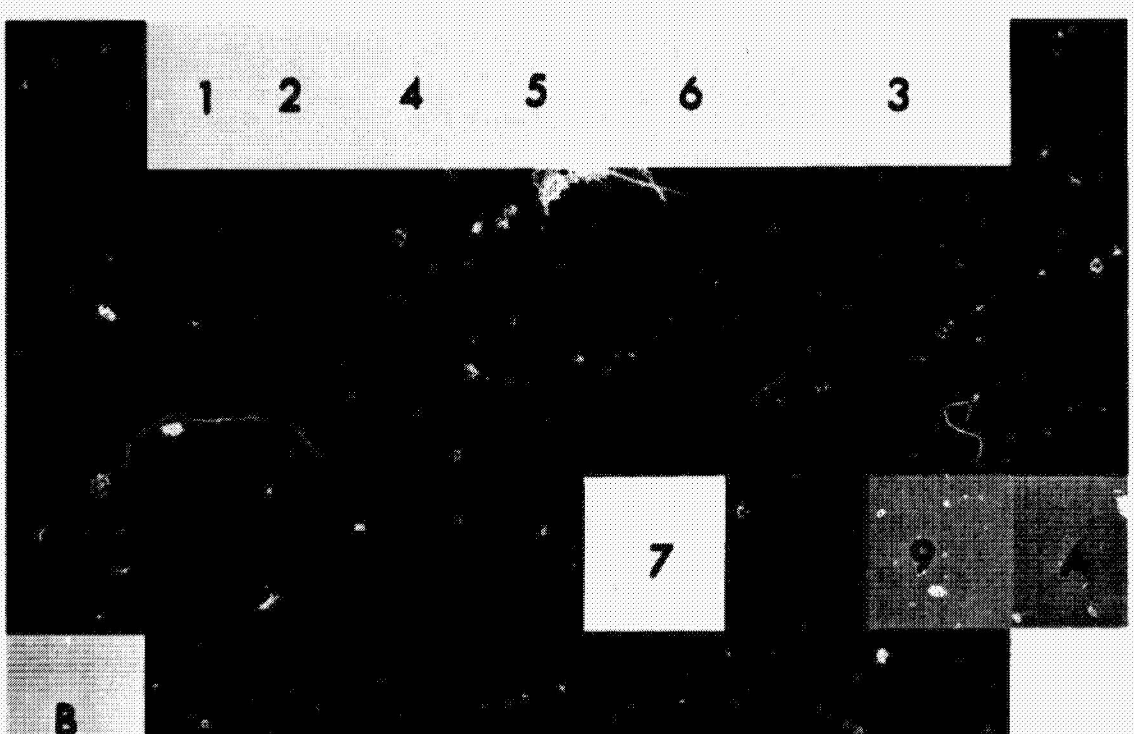


Figure 8-33a.- Color code of Level II water class map of Galveston Study Site. For class symbols, means and diagram, see table 8-XXI, page 8-64, and figure 8-27, page 8-65.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28172

Figure 8-33b.- Level II water class map of Galveston Study Site (imagery acquired November 26, 1972). See figure 8-33a, page 8-74.

9.0 RESULTS OF EVALUATIONS

This section provides the results of the qualitative and quantitative evaluations of the imagery produced from the ERTS-1 data by conventional and computer-aided means. The standard for the evaluations was the identity, location, and spatial extent of the study features as obtained from high-altitude aircraft photography. The performance items evaluated are those stated by the specific objectives of the coastal investigation.

9.1 DETECTABILITY OF COASTAL FEATURES IN THE PROCESSED ERTS-1 DATA

In this report a feature is described as detectable if it can be seen in the imagery as spectrally contrasting to its neighboring features. Detection does not imply spectral uniqueness for a feature in relation to all other features in the scene. Three levels of detectability are noted; never detected, sometimes but not always detected, and always detected (at least in all the data sets considered).

The evaluations of the detectability of the coastal features in the various data types are given in table 9-I.

Some comments on the detectability of coastal features are in order:

1. The only occurrence of a phytoplankton bloom in the ERTS-1 data acquired over the coastal study area up to February 24, 1973, was that which occurred in west Galveston Bay on February 24, 1973 (see figures 7-1

TABLE 9-I.- DETECTABILITY OF COASTAL FEATURES IN PROCESSED ERTS-1 IMAGERY

Feature	Data Type					
	GFSC B&W 240-mm pos. transparencies	NCFV analog color composite	NCFV digital additive color	DAS color composites	Cluster analyses	Maximum likelihood classification
Water	A	A	A	A	A	A
Turbidity zones	A	A	A	A	A	A
Phytoplankton Blooms	A	-	-	-	-	-
Waste/Oil Pollution	N	N	N	S	S	-
Wetlands	S	S	S	S	A	S
Swamp	S	S	S	S	A	S
Marsh	S	S	S	S	A	S
Fresh Marsh	N	N	S	N	A	S
Salt Marsh	A	A	S	A	A	A
Vegetal Assemblages	N	N	N	N	A	S
Nonvegetated Wetland	N	S	S	A	A	A
Algal Mats	N	N	N	N	A	-
Land	S	S	S	A	A	A
Sand	S	S	S	A	A	S
Barrier Flat Veg.	S	A	A	A	A	A
Vegetal Assemblages	N	N	N	N	S	-
Forest	A	A	A	A	A	A
Pine	N	N	N	S	A	-
Hardwoods	N	N	N	S	A	-
Roads (concrete)	A	A	A	A	A	-
Bridges (concrete)	S	S	S	S	S	-
Urban	S	S	S	S	S	-
Rice fields	S	S	S	S	S	-

A – always detected
S – sometimes detected
N – never detected
- – not evaluated

and 7-2). The bloom was exhibited by a bright area in MSS band 6 and a correspondingly dark area in MSS band 4 in the water area. The detected bloom was reddish brown algae *(Exvella balteca)*, which is nontoxic.

2. In general, the conventional processing of fourth-generation film produced better results than that of fifth-generation products (compare figures 7-3 through 7-7, 7-9, 7-12, and 7-13). The analyses of first-generation PMIS DAS black-and-white negative transparencies (figures 7-10 and 7-11) were not clearly superior to the fourth- and fifth-generation products, probably because the PMIS DAS could produce only 16 levels of gray.

3. Some attempts to classify Level II features in the film data were unsuccessful (see figure 7-8).

4. As indicated in table 9-I, the detection of features in the computer-aided processing products was more reliable than in the conventional processing products.

5. An area of water pollution in the Galveston harbor area was detected in the DAS color composite (figure 7-2) made from the ERTS-1 data acquired on August 29, 1972. The same pollution area was detected by the cluster analysis when an area of water was misclassified as low, wet salt marsh (figure 8-19).

9.2 AREAL MEASUREMENT ACCURACY OF COASTAL FEATURES FROM COMPUTER-AIDED PROCESSING PRODUCTS

Two evaluations were made of the areal measurement capability of ERTS-1. The areas were determined by counting feature picture elements and portions of boundary picture elements using the technique given in section 8.0.

In the first case, the area extents of 19 water bodies in the Galveston and Trinity Study Sites were determined from aircraft and ERTS-1 data. An analysis showed that the average absolute error in the measurements of the areal size of water bodies from the ERTS-1 data was 2 hectares (5.2 acres) and was independent of the size of the water body. The areal size of each of the 19 water bodies as derived from aircraft and ERTS-1 data are listed in table 9-II along with the calculation of percent accuracy and absolute error. The locations of the water bodies are shown in figures 9-1 and 9-2. The independency of the absolute value of the

TABLE 9-II.- RESULTS OF AREAL MEASUREMENT OF WATER BODIES IN TRINITY STUDY SITE AND GALVESTON STUDY SITE IN AUGUST 1972.

Water Body	Area (hectares)		% Error	Absolute Error (hectares)
	Aircraft	ERTS-1		
3	246.0	246.8	0.3	0.8
4	61.1	58.1	4.9	3.0
5	63.2	60.3	4.6	2.9
6	34.1	35.8	5.0	1.7
7	28.3	31.4	11.0	3.1
8	20.8	23.7	13.9	2.9
9	11.1	10.0	9.9	1.1
10	13.2	15.5	17.4	2.3
11	5.9	7.4	25.4	1.5
12	6.4	5.9	7.8	0.5
13	1.1	1.3	18.2	0.2
14	2.0	3.4	70.0	1.4
15	8.5	8.9	4.7	0.4
C	10.1	8.9	11.9	1.2
D	37.4	31.8	15.0	5.6
E	20.8	15.6	25.0	5.2
F/G	1.7	1.3	23.5	0.4
H	29.0	30.1	3.8	1.1
M/N	8.5	12.0	41.2	3.5
			Average	2.0

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28088

Figure 9-1. - Trinity Study Site water bodies (photographed August 30, 1972, 2443 film).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

9-6

NASA S 73-28151

Figure 9-2. - Galveston Study Site water bodies (photographed August 30, 1972, 2443 film).

error in the areal measurement from the actual size of the water body is shown in figure 9-3.

In the second case, the areal measurement accuracies were determined for three low, wet, salt marsh areas of predominantly saltmarsh cordgrass (*Spartina alterniflora)* and flooded areas of Gulf cordgrass (*Sparting spartinae)*. These areas, marked as 1, 2, and 3 in the yellow areas of figure 9-4, are the result of an ISOCLS cluster analysis of the August 29, 1972, Galveston Study Site ERTS-1 MSS CCT system-corrected data. These marsh areas are marked as M1, M2, and M3 in the aircraft photograph (figure 9-2, page 9-5). Another analysis of the ERTS-1 data was also made using the NSCLAS clustering algorithm. The areas of these marsh areas were determined by the areal measurement technique given in section 8. The areas were measured also from the aircraft photography obtained over the study site on August 30, 1972. The results of the areal measurements are given in table 9-III.

TABLE 9-III.- RESULTS OF AREAL MEASUREMENT OF SALT MARSH AREAS OF GALVESTON STUDY SITE IN AUGUST 1972

Marsh	Area (hectares)			% Accuracy	
	Aircraft	ISOCLS	NSCLAS	ISOCLS	NSCLAS
1	351.0	350.0	353.0	99.8	99.4
2	77.4	79.6	76.6	97.0	99.0
3	60.5	60.9	67.1	99.2	89.0

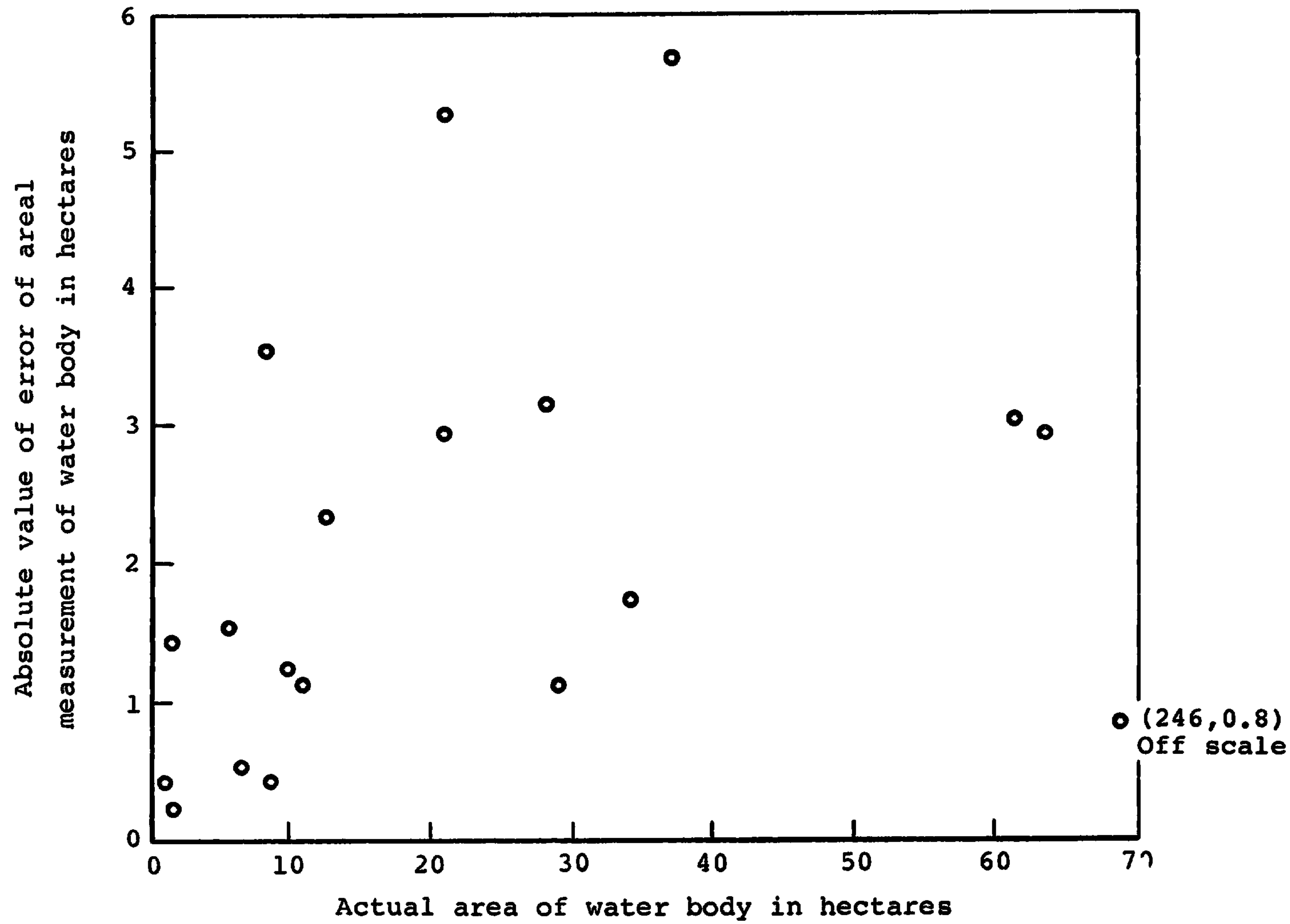


Figure 9-3.– Plot of absolute error of areal measurement versus actual area of 19 water bodies.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

S 73-25503

Figure 9-4.- Level I salt marsh cluster map of Galveston Study Site (imagery acquired August 29, 1972). For color code and cluster identity, see table 8-I, page 8-44, table 8-X page 8-31, and figure 8-9, page 8-33.

In both cases a value of 0.443 hectare was assigned to each picture element unit counted. This number was obtained by dividing the area of one ERTS-1 frame by the total number of picture elements in the frame.

9.3 CLASSIFICATION ACCURACIES OF ISOCLS CLUSTERING PRODUCTS

This section presents the results of the evaluations of the classification accuracies of the cluster maps produced by the computer-aided ISOCLS processing as given in section 8.0. These evaluations were made for the Trinity and Galveston Study Sites and for the ERTS-1 passes of August 29, October 3, and November 26, 1972.

For each study site, a number of test fields were selected for several of the Level I and Level II coastal features. Test fields were not defined for classes that occurred over small areas. Determinations were then made of the number of picture elements within the test fields that were classified as each type of coastal feature.

The following procedure was used in computing the accuracies. At Level II, only the elements that were classified as members of the test-field type were considered to be correct. For example, in a marsh test field that consisted of 283 picture elements, only 222 elements were classified as marsh. The remaining 61 elements were classified as nonmarsh; i.e., either swamp or other. Thus, the Level II classification accuracy was the product of 100(222÷283), or 78.4 percent. For the Level I accuracy computation, both marsh and swamp picture elements were considered correct since they were subsets of the Level I category (wetland), and marsh is a wetland test field at Level I.

Thus, the Level-I classification accuracy for that marsh test field was the product of 100(276÷283), or 98 percent. The results of these evaluations are given in tables 9-IV through 9-IX.

It is appropriate here to give a short discussion of these classification accuracies.

1. The classification accuracies were 100 percent for all of the water test fields. There were, however, some scarce misclassifications of water picture elements as salt marsh, as can be seen by the yellow picture elements scattered about some water areas in figure 8-18, and by the red picture elements in figure 8-19. This red marsh class in the August 29, 1972, clustering analysis was spectrally very close to water, as is shown in the spectral analysis in section 9.5. Also, the presence of oil or waste pollution is indicated in the Galveston harbor area and offshore waters near the left center of figure 8-19. These areas also were misclassified as salt marsh. Thus, the presence of water pollution may be exhibited in the data as a misclassification of known water areas as nonwater.
2. Several fresh and brackish marsh and swamp test fields in the Trinity Study Site had poor classification accuracies in many cases (see tables 9-IV, 9-V, and 9-VI). This was due to the heterogeneous nature of the fresh and brackish marshes in the Trinity Study Site, as well as to the effect of the forest cover over the swamp areas. These results are supported by the spectral analysis given in section 9.5. The major misclassifications in the swamp test fields were mistaking swamp

TABLE 9-IV.- CLASSIFICATION ACCURACIES FOR TRINITY STUDY SITE USING ISOCLS OF AUGUST 29, 1972, DATA

Test Field	Water	Marsh	Swamp	Other	% Correct	
					Level I	Level II
Water	100[a]	0	0	0	100	-
Water	108	0	0	0	100	-
Marsh	0	99	0	55	64.3	64.3
Marsh	0	57	0	51	52.8	52.8
Swamp	2	0	45	2	91.8	91.8
Swamp	0	0	14	28	33.3	33.3
Other (Pine)	0	0	0	60	100	-
Other (Urban)	0	2	0	73	97.3	-

[a]Number of picture elements in a given test field that were classified as a given class.

TABLE 9-V.- CLASSIFICATION ACCURACIES OF TRINITY STUDY SITE USING ISOCLS FOR OCTOBER 3, 1972, DATA

Test Field	Water	Marsh	Swamp	Other	% Correct	
					Level I	Level II
Water	100	0	0	0	100	-
Water	108	0	0	0	100	-
Marsh	0	85	9	60	61.0	55.2
Marsh	11	63	11	23	68.5	58.3
Swamp	0	2	47	0	100	95.8
Swamp	4	100	7	242	30.3	2.0
Other (Pines)	1	0	3	200	98.0	98.0
Other (Mixed)	0	2	0	58	96.7	96.7

TABLE 9-VI.- CLASSIFICATION ACCURACIES USING ISOCLS, TRINITY STUDY SITE, NOVEMBER 26, 1972

Test Field	Water	Marsh	Swamp	Nonveg Wetland	Sand	Other	% Correct	
							Level I	Level II
Water	100	0	0	0	0	0	100	-
Water	108	0	0	0	0	0	100	-
Marsh	0	222	54	0	0	7	98.0	78.4
Marsh	3	110	30	0	0	19	86.4	67.9
Swamp	0	7	42	0	0	9	100	85.7
Swamp	4	106	122	3	0	79	72.6	50.4
Other (Pine)	0	0	0	0	0	100	100	100

TABLE 9-VII.- CLASSIFICATION ACCURACY OF GALVESTON STUDY SITE USING ISOCLS FOR AUGUST 29, 1972, DATA

Test Field	Water	Marsh	Sand	Vegetation	Other	% Correct	
						Level I	Level II
Water	396	0	0	0	0	100	-
Water	576	0	0	0	0	100	-
Marsh	5	60	0	0	0	92.3	92.3
Marsh	2	111	0	0	0	98.2	98.2
Vegetation	0	0	0	120	0	100	100
Vegetation	0	0	0	72	2	100	97.3
Other (Urban)	0	0	0	0	62	100	100
Other (Urban)	0	0	0	0	145	100	100

TABLE 9-VIII.- CLASSIFICATION ACCURACIES OF GALVESTON STUDY SITE USING ISOCLS FOR OCTOBER 3, 1972, DATA

Test Field	Water	Marsh	Sand	Vegetation	Other	% Correct	
						Level I	Level II
Water	270	0	0	0	0	100	-
Water	638	0	0	0	0	100	-
Marsh	0	119	1	1	0	98.3	98.3
Marsh	11	129	0	0	0	92.1	92.1
Vegetation	0	0	0	67	5	100	93.1
Vegetation	0	13	0	137	0	91.3	91.3
Other (Urban)	0	0	6	7	76	100	85.4
Other (Urban)	0	6	18	2	58	92.9	69.0

TABLE 9-IX.- CLASSIFICATION ACCURACY OF GALVESTON STUDY SITE USING ISOCLS FOR NOVEMBER 26, 1972, DATA

Test Field	Water	Marsh	Nonveg Wetland	Vegetation	Other	% Correct	
						Level I	Level II
Water	338	0	0	0	0	100	-
Water	180	0	0	0	0	100	-
Marsh	2	126	0	0	0	98.3	98.3
Marsh	0	62	2	1	0	98.5	90.6
Vegetation	0	0	0	35	0	100	100
Vegetation	0	9	0	58	0	86.6	86.6
Other (Urban)	0	0	9	6	46	85.3	76.7
Other (Urban)	0	6	3	16	28	83.0	52.8

for forest or for marsh. The major misclassifications in the marsh test fields were mistaking marsh for dry grassland or for swamp.

3. There was little misclassification of the salt marsh areas because of their spectral homogeneity and distance from other features. (See the classification accuracies for the Galveston marsh test site, which is all salt marsh.)

4. Many rice fields were classified as marsh or swamp because of their spectral similarity.

5. Boundary picture elements between dry land and water areas, such as along beaches and rivers, were classified as either marsh or nonvegetated wetland.

6. Elements of the clusters identified as sand also fell in known urban areas. Thus, sand and urban areas had similar ERTS-1 spectral properties (see figures 8-18, 8-20, and 8-22).

7. The class nonvegetated wetland was accurately depicted in the cluster data (the brown areas in figures 8-18, 8-20, and 8-22), although some urban areas were misclassified as nonvegetated wetland.

8. Barrier flat vegetation was accurately classified, as shown in figures 8-18, 8-20, and 8-22.

The following items describe other aspects of the classification of coastal features by computer-aided clustering processing.

1. Two water clusters (L and S in table 8-V) out of all the water clusters produced by clustering analyses had

peculiar spectral properties in that they did not lie on the usual water sequence in the cluster diagram (figure 8-6). The elements of these clusters fell in stagnant water areas (light and dark green in figure 8-14) in the Trinity August 29, 1972, scene. These cluster properties were hypothesized to be the result of the influence of green algae in the stagnant water at the end of a fairly rainless summer.

2. With the exception of the previously noted algal-influenced water, the clusters that represented water fell near a gently curving line in the plot of their centers in MSS bands 4 and 7. When each of these clusters was displayed as separate colors (figures 8-1[illegible], 8-15, and 8-23), a map showing zones of turbidity was constructed, since it was established that the major cause of changes in water reflectance in the ERTS-1 spectral bands was surface turbidity changes. (Additional discussion is provided in appendix A.)

3. The display of subclusters in the marsh gro[illegible] as separate colors (figures 8-16, 8-19, and 8-21) and the display of subclusters in the barrier flat vegetation groups as separate colors (figure 8-22) showed that there was a fairly smooth transition between low, wet marsh subgroups through higher, drier marsh groups and on through barrier flat vegetation zones. This transition was exhibited in MSS bands 6 and 7, and the transition was concluded to be related to the percentage of open water and soil moisture variations, not to the changes in vegetal type. A similar transition was noted in an area of grass vegetation that was flooded in August 1972 and dried out by the end of November 197[illegible]. This area is marsh area number 1 in figure [illegible]-1.

4. Subresolution features such as bridges, causeways, jetties, dikes, beaches, and roads, as well as boundary elements, were classified as features spectrally between the subresolution features' spectral properties. For example, boundaries of beach and water, as well as bridges, jetties, and causeways, were classified as nonvegetated wetland.

5. Pine and hardwood forest were separable in all three sets of ERTS-1 Trinity Study Site data; e.g., figure 8-15, where hardwood is green and pine is red. (Recall that these three sets were obtained in late summer and fall.)

6. Finally, the cluster diagrams (even-numbered figures 8-6 through 8-12) were useful in identifying clusters that had been formed by program ISOCLS.

9.4 CLASSIFICATION ACCURACIES OF LARSYS MAXIMUM-LIKELIHOOD CLASSIFICATION PRODUCTS

This section presents the results of the evaluations of the classification accuracies of the classification maps produced by the LARSYS maximum-likelihood classification processing on the ERIPS, CYBER 73, and PMIS DAS (section 8.0). These accuracies were evaluated in a manner similar to the ISOCLS clustering products. The Trinity and Galveston Study Site data acquired on October 3 and November 26, 1972, were evaluated.

The results of these evaluations are given in tables 9-X through 9-XIII, and a few comments on these results follow.

1. There were major problems with the classification of the water areas in the Galveston Study Site data of

TABLE 9-X.- TEST FIELD ACCURACIES OF TRINITY STUDY SITE USING LARSYS ON OCTOBER 3, 1972, DATA

Test Field	Water	Marsh	Swamp	Other	Threshold	% Correct	
						Level I	Level II
Water A	134	0	0	0	1	99.3	-
Water B	135	6	0	0	3	93.8	-
Marsh A	10	104	1	2	1	89.0	88.1
Marsh B	0	200	0	23	0	89.3	89.3
Swamp A	0	20	109	12	2	90.2	76.2
Swamp B	0	13	59	5	0	93.5	76.6
Swamp C	0	31	9	1	5	87.0	19.6
Other (pine)	0	1	21	141	0	86.5	86.5
Other (hardwoods/ pine)	0	3	44	13	0	21.7	21.7
Other (urban)	0	13	0	100	3	86.2	86.2

TABLE 9-XI.- TEST FIELD ACCURACIES OF TRINITY STUDY SITE USING LARSYS ON NOVEMBER 26, 1972, DATA

Test Field	Water	Marsh	Swamp	Sand	Other	Threshold	% Correct	
							Level I	Level II
Water	354	0	0	0	0	6	98.3	-
Water	134	0	0	0	0	9	93.7	-
Marsh	0	61	16	0	5	26	93.9	56.5
Marsh	0	99	6	3	23	64	53.8	50.8
Swamp	0	1	66	1	0	13	82.7	81.5
Swamp	0	3	55	0	0	7	89.2	84.6
Other (pine)	0	0	0	0	187	37	83.5	83.5
Other (vegetation)	0	1	0	0	143	21	86.7	86.7

TABLE 9-XII.- TEST FIELD ACCURACIES OF GALVESTON STUDY SITE USING LARSYS ON OCTOBER 3, 1972, DATA

Test Field	Water	Marsh	Tidal Flat	Sand	Vegetation	Other (Urban)	Threshold	% Correct	
								Level I	Level II
Water	84	73	0	0	0	0	3	52.5	-
Water	71	7	0	0	0	0	11	79.8	-
Marsh A	0	88	0	7	0	0	11	77.7	77.7
Marsh B	0	76	2	0	0	0	10	88.6	86.4
Tidal Flat	0	0	76	20	0	0	0	79.2	79.2
Tidal Flat	0	0	58	6	0	0	13	75.3	75.3
Vegetation	3	0	0	4	80	0	11	85.7	81.6
Vegetation	0	0	7	6	68	4	11	81.2	70.8
Other (urban)	0	0	0	3	4	187	6	97.0	93.5
Other (urban)	0	0	0	20	47	49	35	76.8	32.5

TABLE 9-XIII.- TEST ACCURACIES OF GALVESTON STUDY SITE USING LARSYS ON NOVEMBER 26, 1972, DATA

Test Field	Water	Marsh	Tidal Flat	Sand	Vegetation	Other	Threshold	% Correct	
								Level I	Level II
Water	297	0	0	0	0	0	3	99.0	-
Water	10	0	0	0	0	0	300	3.2	-
Marsh	3	87	4	0	0	0	18	81.3	77.7
Marsh	0	30	5	0	0	1	9	77.8	66.7
Tidal flat	0	0	49	3	0	0	10	79.0	79.0
Vegetation	0	0	0	0	167	31	16	92.5	78.0
Vegetation	0	0	0	5	54	3	30	67.4	58.7
Other (urban)	0	0	0	0	15	165	13	93.3	35.5
Other (urban)	0	0	0	0	4	94	6	94.2	90.4

October 3, 1972 (table IX-11) and November 26, 1972 (table 9-XII). First, one marsh training field (test field 2) contained a significant amount of open water (see table VIII-20 and figure 8-26), so that it was spectrally between water and marsh. In the resulting classification maps (figures 8-30 and 8-31), this class (purple in the figures) appeared over large portions of the water. The unsupervised clustering processing of the same data did not have this problem. Second, significant portions of the Gulf of Mexico were unclassified (black areas in figures 8-32 and 8-33). This problem was created by the absence of a training field over clear ocean water. This example highlights the problem with supervised classification of choosing training fields to cover the whole range of spectral properties of a feature. This is difficult in advance of the analysis, especially for variable features such as water.

2. Confusion existed between swamp and forest in the maximum-likelihood classification analysis for the October 3, 1972, Trinity Study Site. (See the purple swamp areas in figure 8-28.) This confusion was much lessened in the November 26, 1972, data (purple swamp areas in figure 8-29). This improvement could have been due to the thinning of the forest cover over the swamp.

3. Marsh areas in the Trinity Study Site were poorly classified by the maximum-likelihood classifier mainly because of the incompleteness of training fields in representing all types of fresh and brackish marsh.

9.5 SPECTRAL UNIQUENESS AND TEMPORAL PROPERTIES OF COASTAL FEATURES IN ERTS-1 DATA

This section presents the results of the analysis of ERTS-1 spectral reflectance signatures of the coastal study features. A spectral reflectance signature is a plot of feature reflectances versus ERTS-1 MSS band numbers. The reflectances for this analysis were deduced from the cluster or class means for the features identified in previous sections. These deductions were made through the use of the ROTAR technique explained in section 8.0.

The plots of the ERTS-1 spectral reflectances of various coastal features versus the four MSS bands are shown in the following figures. These plots will be referred to simply as the "signatures".

The ERTS-1 signatures of a number of water areas in the coastal study area are shown in figure 9-5. Signature 5 is of the clear ocean water about 25 kilometers offshore of Galveston Island in the Gulf of Mexico. Signature 1 is the most reflective of all water signatures and was deduced from cluster 6 in the clustering analysis of the Trinity Study Site data acquired November 26, 1972. This signature represented the very turbid water that was flowing into Lake Anahuac from Turtle Creek. Signature 2 represents the rest of the Lake Anahuac water on November 26, 1972. In the case of signature 5, the peak reflectance of the water was in MSS band 4 (green) and was three times as reflective as MSS band 5 (yellow-red). Signature 1 represents the most turbid, and this water reflectance was highest in MSS band 5. Signatures 1 and 2 also represent water areas that were probably well mixed in sediment content with depth, since

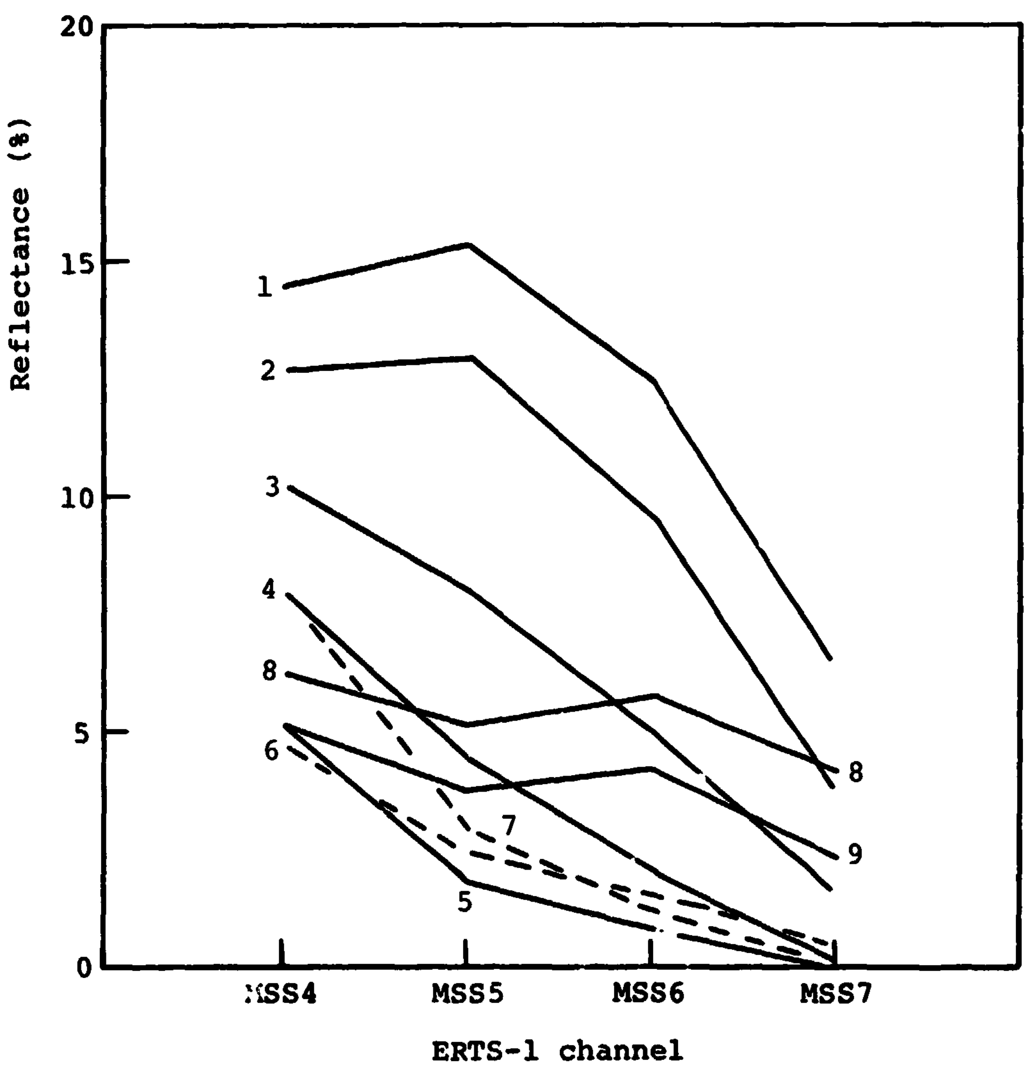


Figure 9-ↄ.– ERTS-1 signatures of water.

the water masses were not far from their source, Turtle Creek. Signatures 3 and 4 were obtained from moderately turbid water in the Galveston Bay complex.

Signatures 8 and 9 represent a stagnant water area in the Trinity Study Site on August 29, 1972. The relative near-infrared reflectances (MSS bands 6 and 7) were significantly higher for this signature compared to other water signatures. Although no ground truth was taken at the time of the August 29, 1972, ERTS-1 overpass, it is reasonable to assume that the ponds contained a large population of algae, probably green algae, algal mats, or surface aquatic vegetation. Signature 6 was taken over the Houston Lighting & Power Company's cooling pond in the Trinity Study Site and shows more green-band absorption than other water areas.

The signatures in figure 9-5 represent a predominantly smooth transition from clear to very turbid water, with the exception of water covered by an algal mat.

The next set of signatures deal with wetland Level II and Level III features. Three signatures of a portion of the Trinity delta swamplands have been deduced (see figure 9-6). Signatures 1, 2, and 3 were obtained from ERTS-1 data acquired on August 29, October 3, and November 26, 1972, respectively. The decrease in infrared reflectance for signature 3 is probably due to the decrease in the leaf cover as the area began to flood and the leaves of the hardwood overcover began to die and fall.

The signatures for the salt marsh, predominantly marshhay cordgrass (*Spartina alterniflora*), and the boundaries of

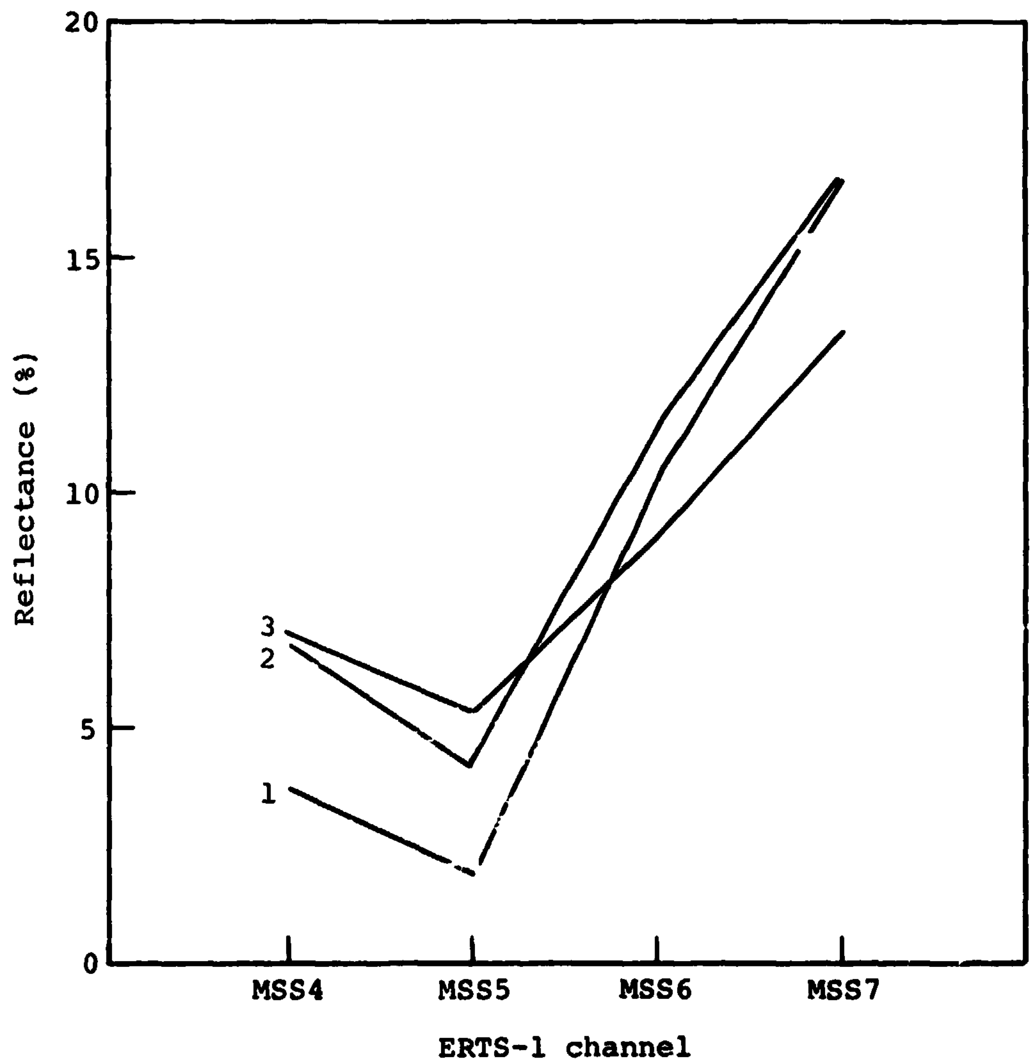


Figure 9-6.– ERTS-1 signatures of swamp.

West Bay near Galveston Island are shown in figure 9-7. Signatures 1, 2, and 3 represent the Level III marsh on August 29, October 3, and November 26, 1972, respectively.

Signatures of nonvegetated wetland areas are shown in figure 9-8 Signatures 1, 3, and 4 are of tidal flats that are basically wet-sand areas of the nonvegetated wetland class.

The ERTS-1 signatures of the feature dry sand are shown in figure 9-9. Signatures 1, 2, and 3 were deduced from the cluster means for sand in the Galveston Study Area for August 29, October 3, and November 26, 1972, respectively. Signature 4 was deduced from the beach training field statistics for the Galveston October 3, 1972, data. There is a wide variation in the overall reflectance level of sand, probably due to differences in sand wetness and also that sand clusters are based on nonsand picture elements, such as industrial and concrete urban areas. Also, wet-sand signatures appear to form a continuum with nonvegetated wetland signatures.

Figure 9-10 shows signatures of some of the dry, natural grassland areas that cover the vegetated portions of the barrier island. Signatures 1, 2, and 3 were deduced from ERTS-1 data obtained on August 29, October 3, and November 26, 1972, respectively.

Figures 9-11 and 9-12 illustrate the ERTS-1 signatures of a pine forest and a deciduous forest, respectively. Signatures 1, 2, and 3 in both figures are based on the ERTS-1 data acquired August 29, October 3, and November 26, 1972,

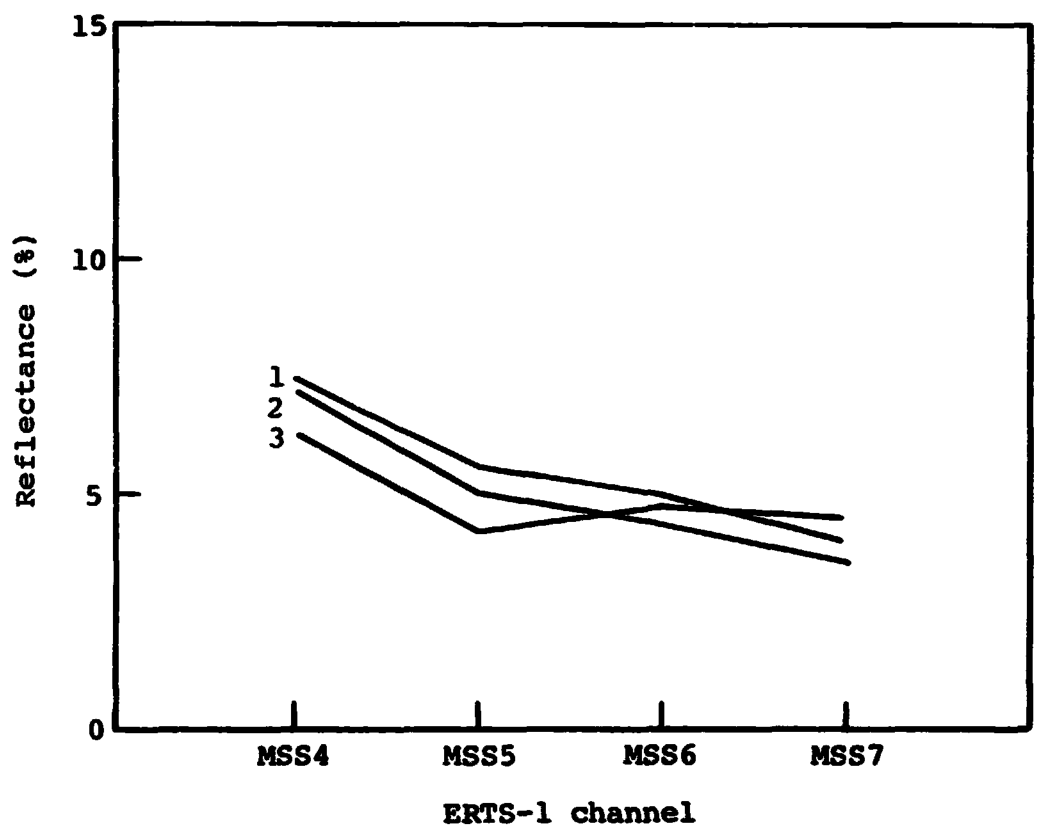


Figure 9-7.— ERTS-1 signatures of salt marsh (*Spartina alterniflora*).

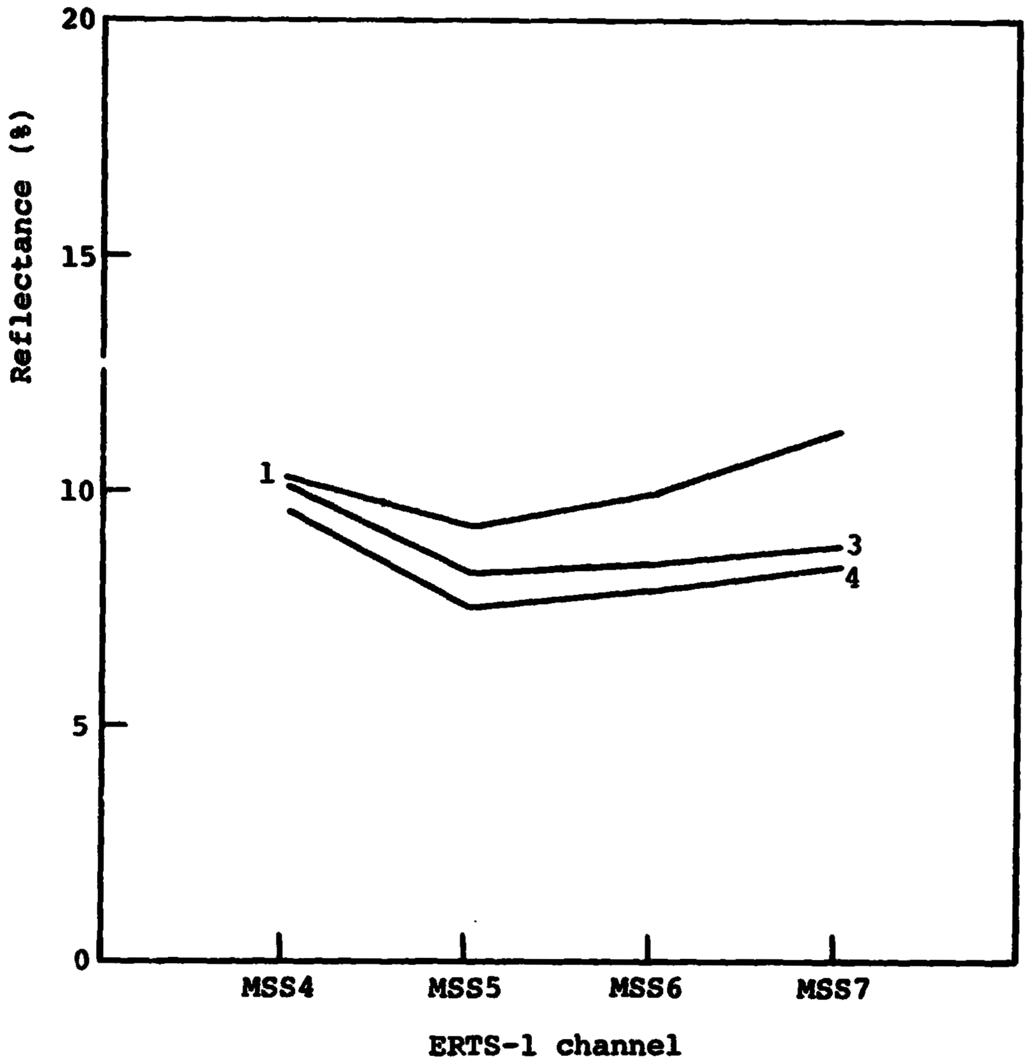


Figure 9-8.— ERTS-1 signatures of wet sand and algal mats.

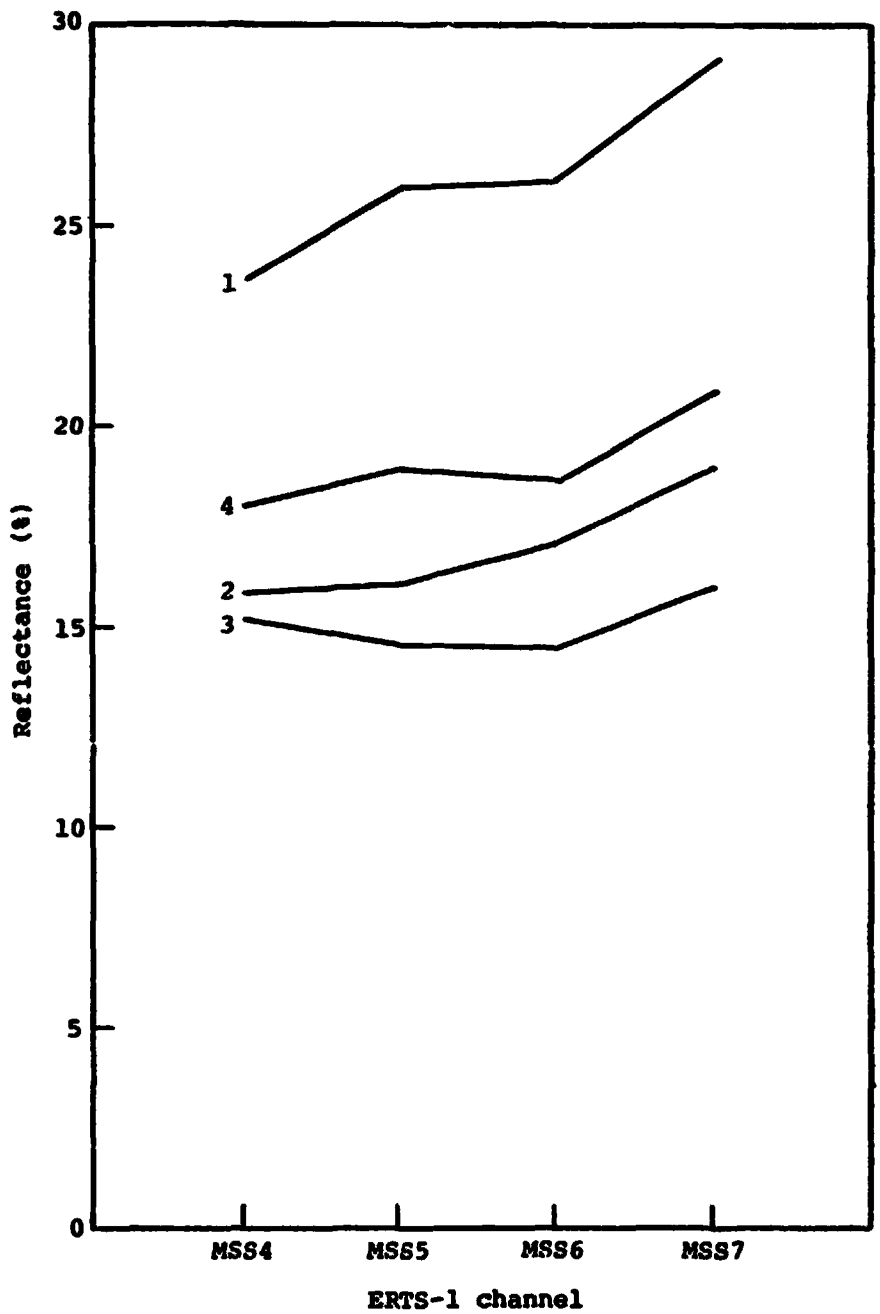


Figure 9-9.- ERTS-1 signatures of dry sand.

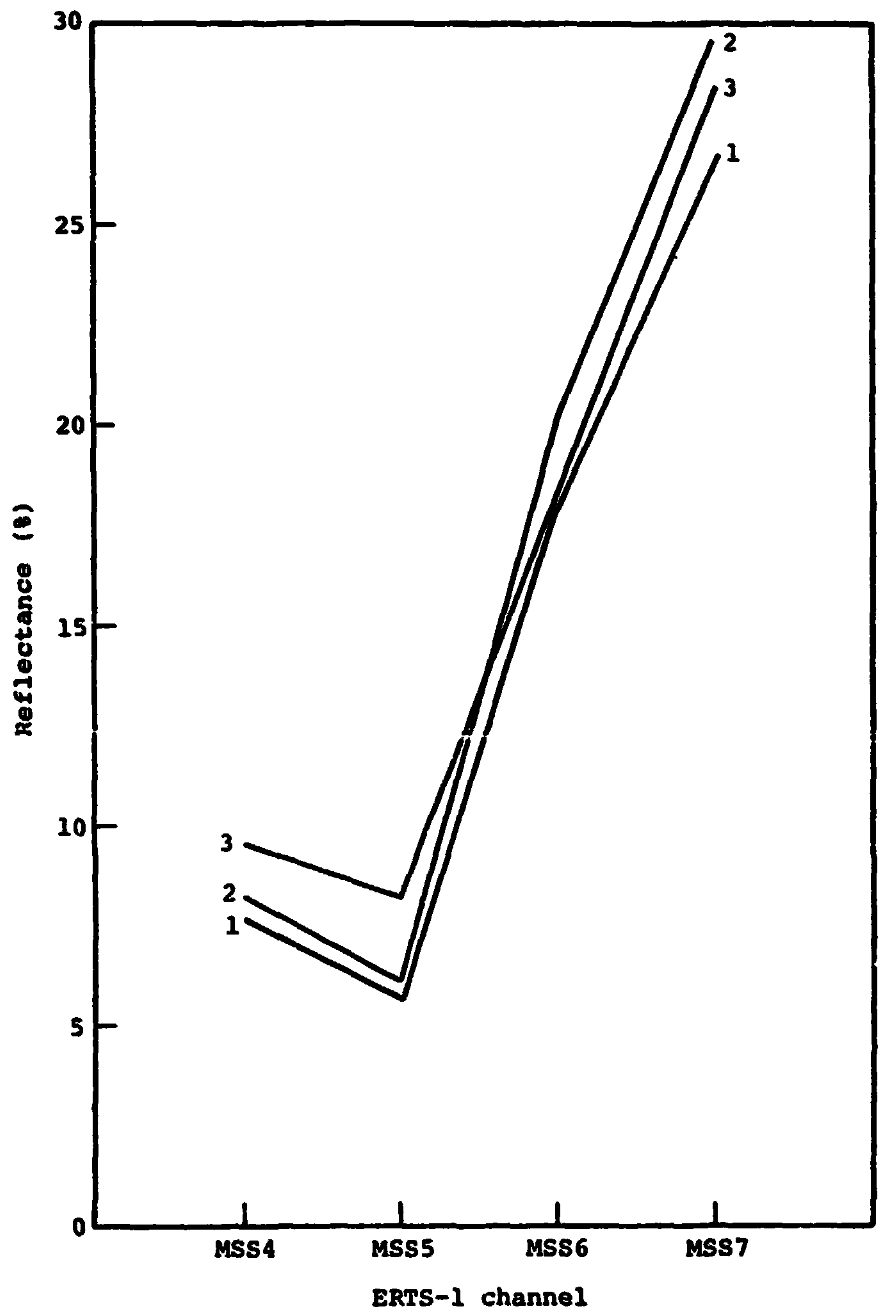


Figure 9-10.- ERTS-1 signatures of dry natural grassland.

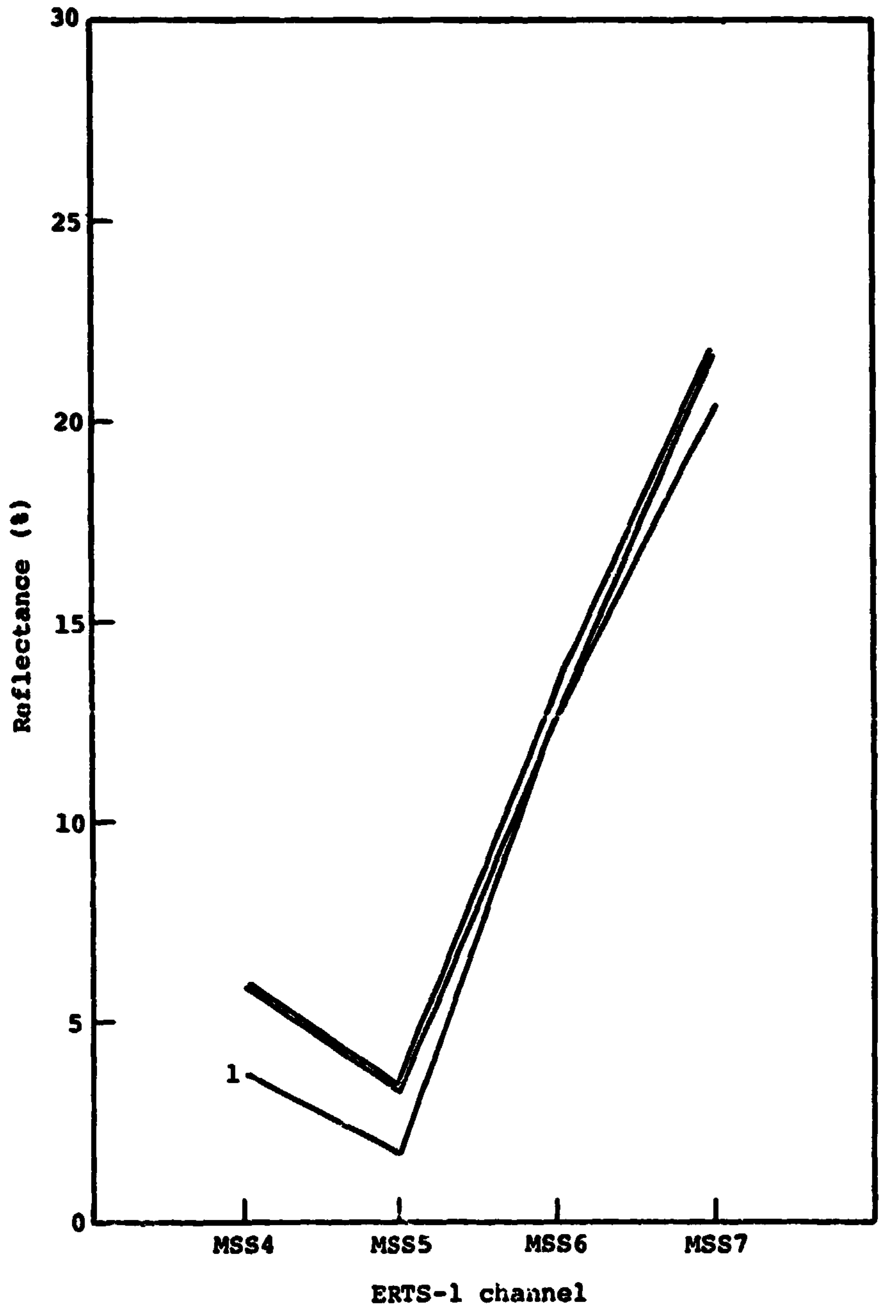


Figure 9-11.- ERTS-1 signatures of pine forest.

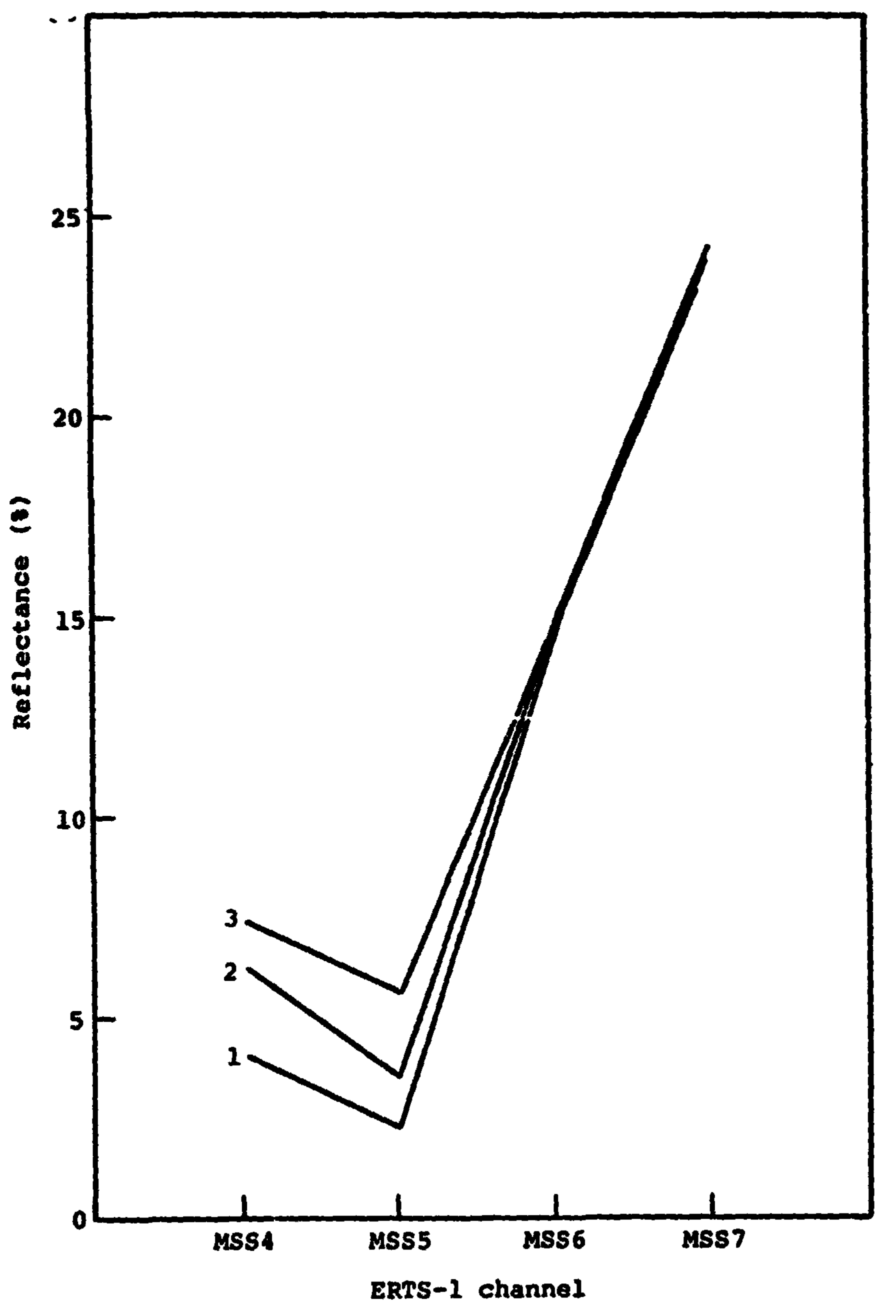


Figure 9-12.- ERTS-1 signatures of a deciduous forest.

respectively. The pine signatures and hardwood signatures were consistent in the infrared bands with time.

A cross section of signatures is displayed in figure 9-13 for the transition from water (2) to very dry grass (Q) in the marsh region of the Trinity Study Site on October 3, 1972. The visible reflectances of all wetland and dryland classes were very similar. Signatures 5 and 7 represent low marsh areas, D is a boundary class, and H, N, and Q represent high, dry marsh areas. The symbols 2, 5, 7, D, H, N, and Q correspond to cluster symbols in the October 3, 1972, Trinity Study Site cluster analysis.

A similar cross section of signatures for the Galveston Island transect is shown in figure 9-14. Signatures C, P, 4, I, F, N, B, and J correspond to the clusters produced in the October 3, 1972, Galveston Study Site clustering analysis. Signature 1 is taken from training field statistics for sand. Signature C is water, signature P is the salt marsh signature, which is primarily marshhay cordgrass.

Signatures 4 and I are salt marsh areas that are drier than P, and signatures F, N, B, J, and 3 are dry salt marsh and grassland areas on the barrier flat. The visible signatures of salt marsh grasses vary from the dry grasses in the fresh and brackish marsh (compare figures 9-13 and 9-14).

Representative signatures from all the classes discussed in the foregoing are shown in figure 9-15. Each signature is unique for October 3, 1972, with the exception of sand and urban areas, which are combined.

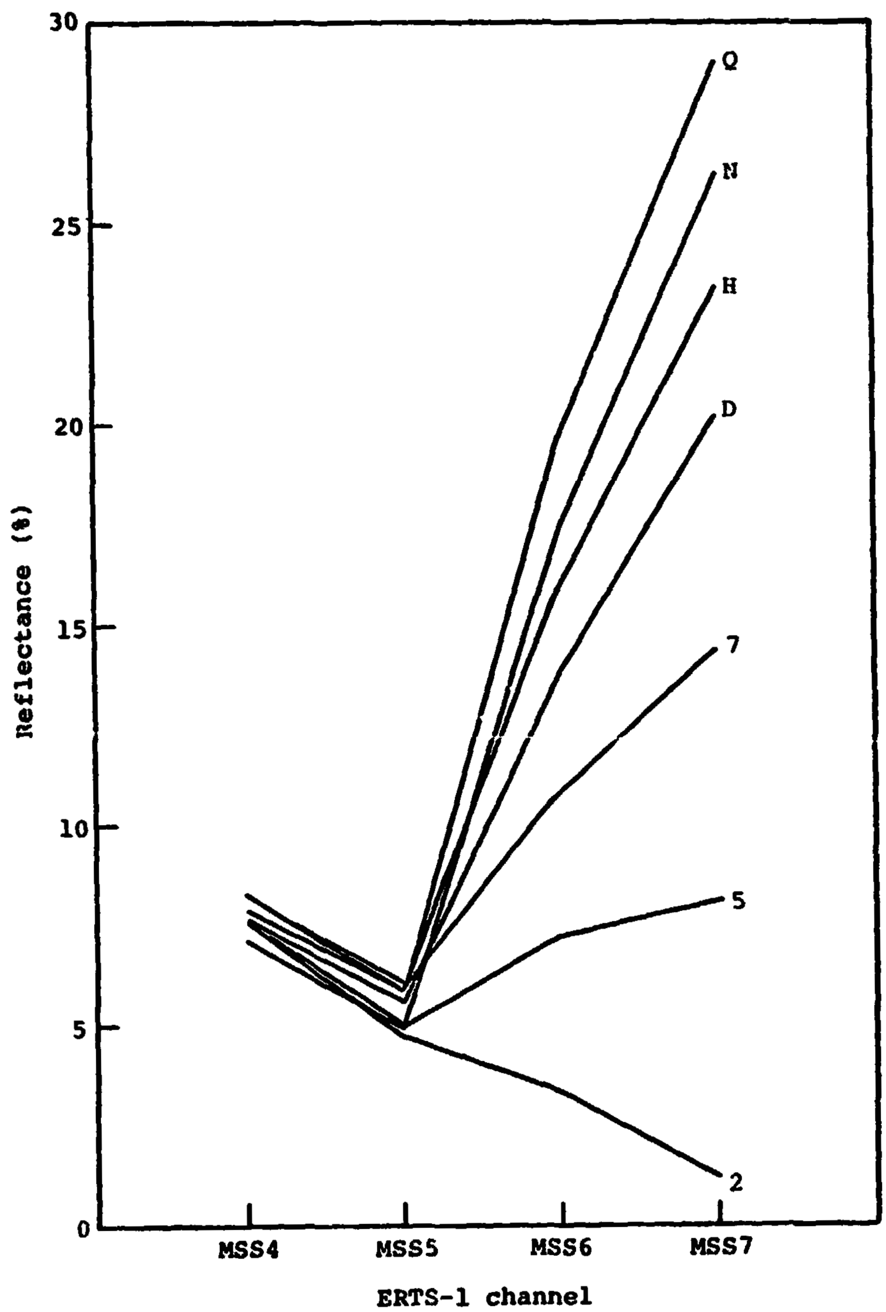


Figure 9-13.- Cross section of October 3, 1972, ERTS-1 signatures of Trinity Study Site based on ISOCLS.

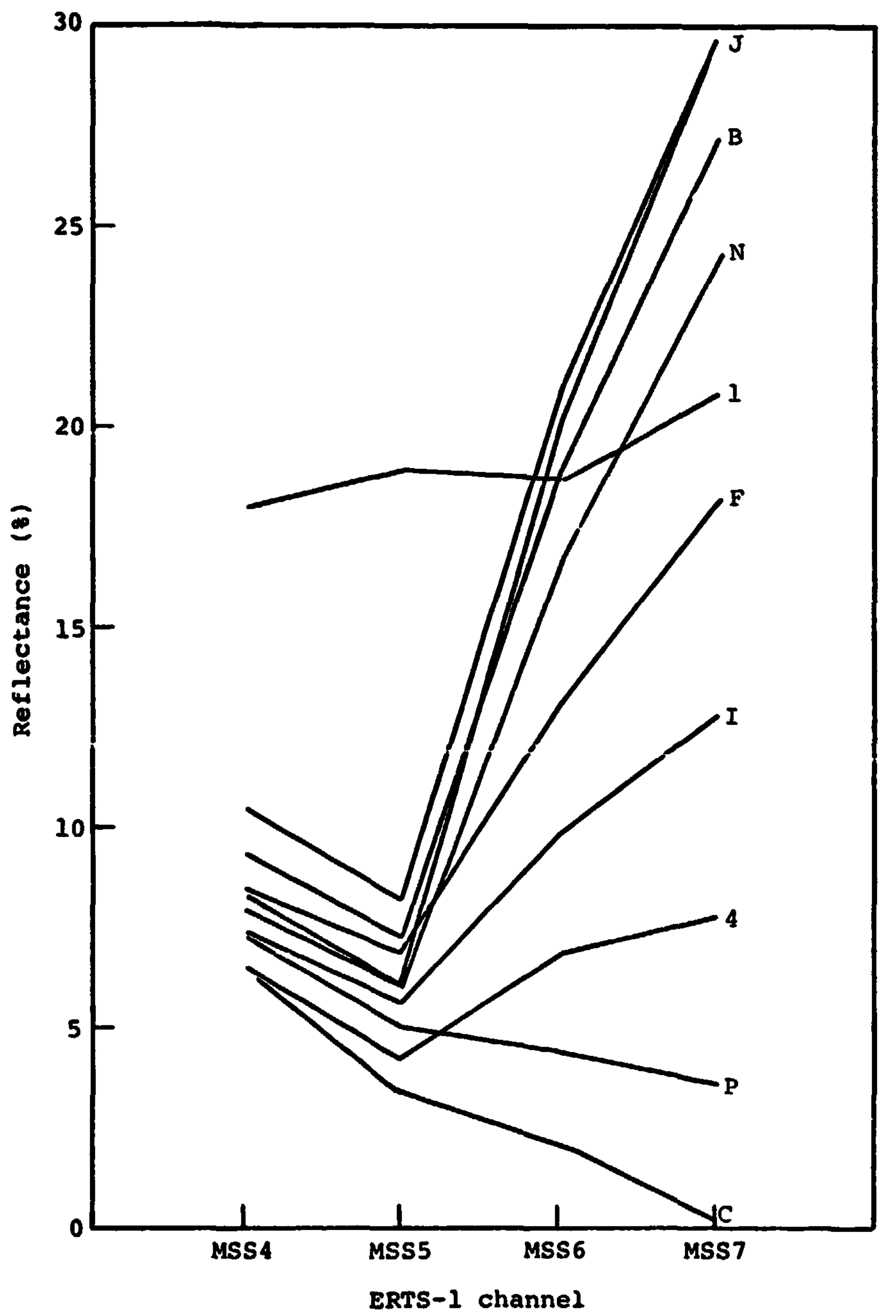


Figure 9-14.- Cross section of October 3, 1972, ERTS-1 signatures of Galveston Study Site based on ISOCLS.

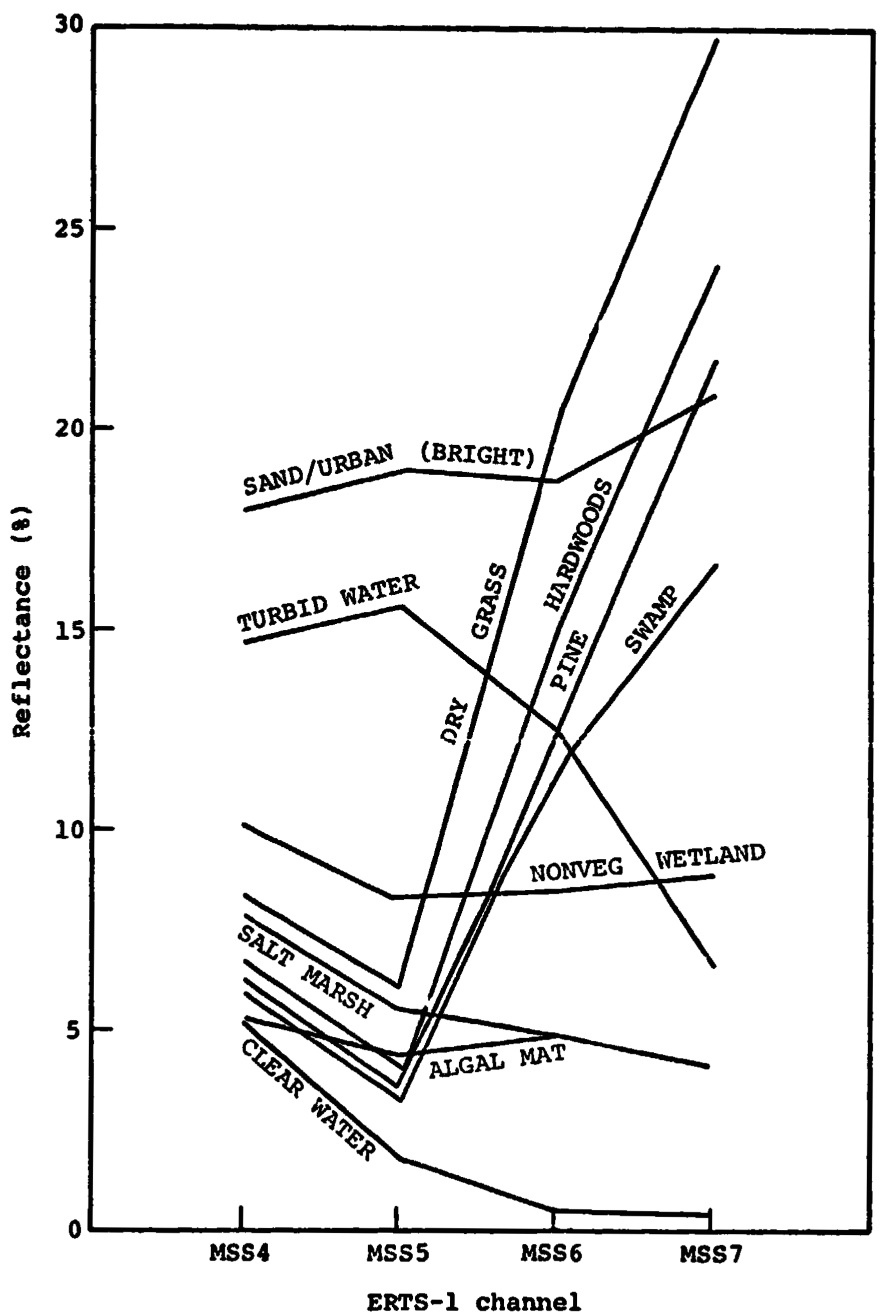


Figure 9-15.- Representative signatures of coastal zone features.

A plot of the ERTS-1 reflectances of all coastal features (all three months and all three sites) in MSS bands 5 and 7 (figure 9-16) shows that the signatures are unique, even with time. The partitions in figure 9-16 are valid only for the data in the figure and may change when more data are added. The closeness of signatures in some cases indicates problem areas for spectral classification. The corresponding plot of grayscale signatures (figure 9-17) shows that grayscale signatures are not unique except for water and most sand areas.

In summary, the evaluation of all coastal signature features showed the following:

1. Water, wetland, and land features are not represented by a single reflectance signature in each case; rather they are represented by a family of signatures. For example, water is represented by a family of signatures, a continuum in spectral space from clear water to the most turbid water. In the case of land and wetland, the family of curves is discontinuous and is broken into several subfamilies as discussed below.

2. Wetland is represented by three families of signature curves. The first is the marsh family, which is a continuum from marsh areas that are almost totally inundated to marsh areas that are practically dry. The second is the swamp family, which is a continuum from water-dominated areas to forest-covered areas. The third is the nonvegetated wetland family, which is a continuum from wet sand to moist sand. Algal mats in water areas also have a unique signature.

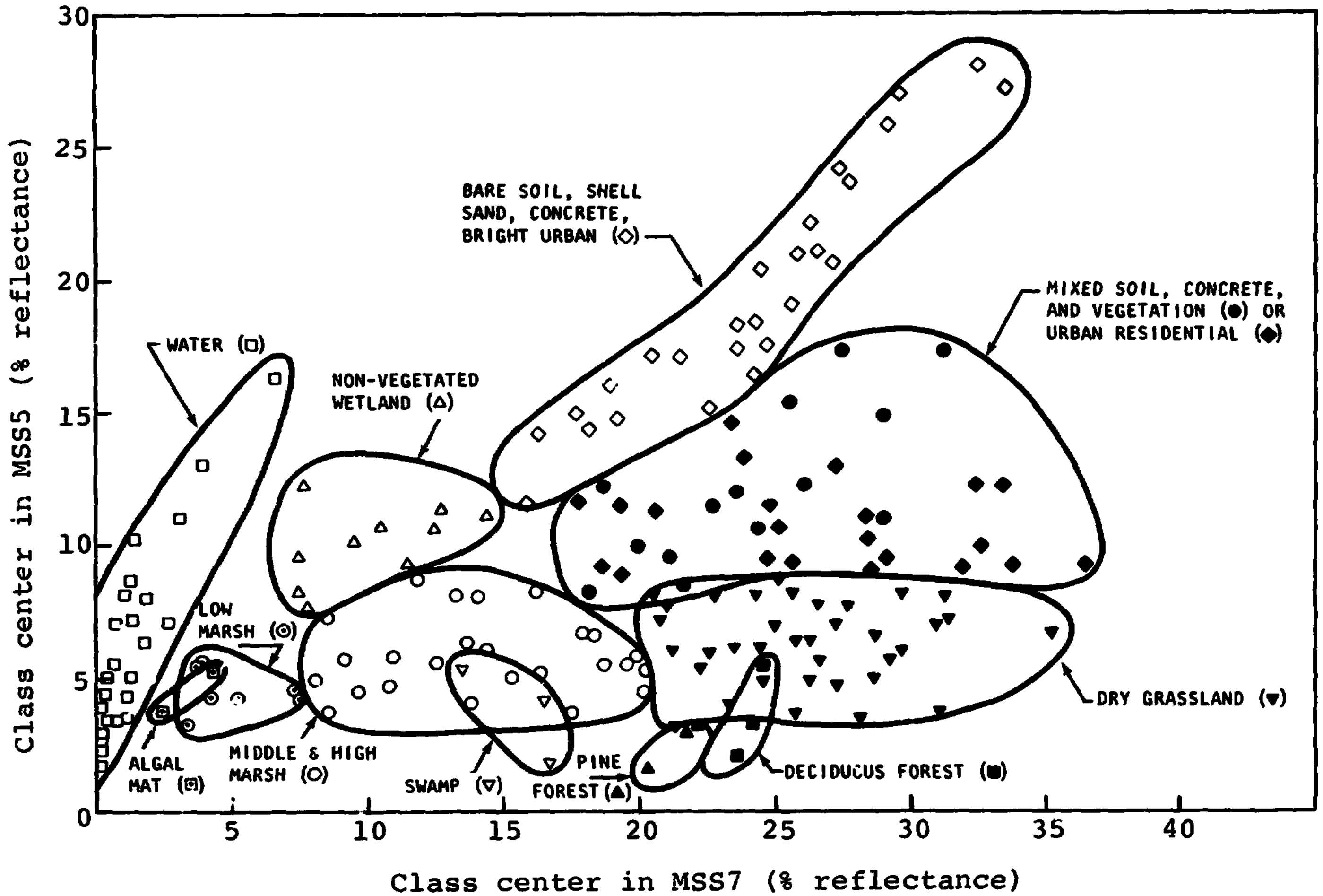


Figure 9-16.- ERTS-1 reflectance signatures of coastal features in Mss bands 5 and 7. (Data taken from all cluster analyses.)

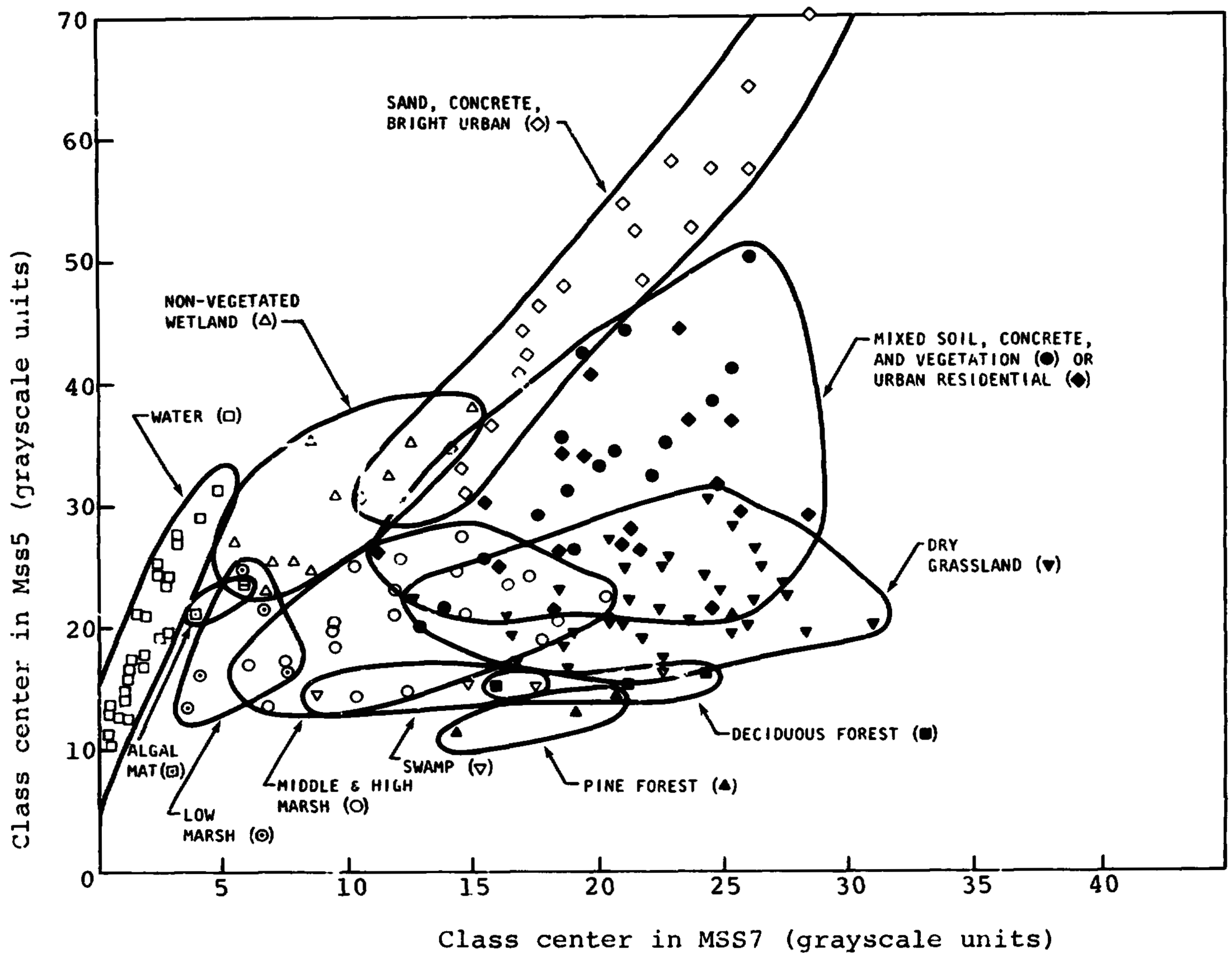


Figure 9-17.- ERTS-1 grayscale signatures of coastal features in MSS bands 5 and 7. (Data taken from all cluster analyses).

3. Land is represented by a diverse number of signature families. The coastal investigation did not consider many of these, such as crops, except rice, and barren land, except sand. Sand was found to be represented by a family of curves representing probably different wetness zones. Also, the sand family formed a continuum with the nonvegetated wetland family. Grasslands and forest were represented by a vegetation family of signatures from pine forest to hardwood forest to dry grasslands. Urban signatures were complex and were often confused with vegetation or sand signatures.

9.6 TEMPORAL ANALYSIS

In the Trinity Study Site, two sets of ERTS-1 data were registered to create one eight-channel tape. The first four channels contained the August 28, 1972, data and the last four channels contained the November 26, 1972, data. The MSS7 data from each date were combined on the PMIS DAS using green for August 28, 1972, and red for November 26, 1972. The resulting image is shown in figure 9-18. Areas of little change show as shades of yellow (red + green). Areas of change show as shades of red or green where brown areas have less coverage of water in November than in August and green areas have more coverage of water in November than in August. Note the swamp and ricefield areas (regular-shaped areas) and tidal zone (irregular brown area along bay coast). This image demonstrates the potential for temporal analysis of ERTS-1 data for classifying features that show as areas of change in reflectance properties.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

Figure 9-18.- Result of combined image of MSS7 ERTS-1 data on August 28 (green) and November 26 (red), 1972.

10.0 CONCLUSIONS AND RECOMMENDATIONS

The ERTS-1 MSS system-corrected data contain adequate information upon which surveys of certain coastal features can be based. The adequacy and accuracy of the information depends on the coastal features selected and the processing system.

The attempts to map coastal features from ERTS-1 MSS system-corrected film data resulted in limited successes. Water bodies, water turbidity zones, phytoplankton blooms, salt marshes, grasslands, forest, and sand/urban areas were detected and mapped in all of the film data. Oil/waste pollution, swamp, fresh and brackish marshes, and nonvegetated wetland could not be detected and mapped consistently from film data. These results were based on fourth- and fifth-generation film products.

The attempts to map coastal features from ERTS-1 MSS system-corrected computer-compatible-tape (CCT) data were successful in general. Water bodies, water turbidity zones, wetlands, marshes (fresh, brackish, and salt), nonvegetated wetlands, algal mats, swamps, land, sand, dry grasslands, forest (pine, mixed pine, and hardwood), major roads, urban areas, major bridges, and flooded ricefields were detected and mapped in all processed CCT data with consistency. Oil/waste pollution was detected on one occasion only as a misclassification of a known water area as salt marsh.

The results of the unsupervised ISOCLS clustering products were more accurate and generally more suitable in mapping coastal features than were the products of the supervised LARSYS maximum-likelihood classification. This was due to the spectral heterogeneity of the coastal features on the ERTS-1 scale; this heterogeneity made the selection of training fields difficult and resulted in feature statistics that did not fully represent the feature class. The overall classification accuracies for the ISOCLS and LARSYS computer-aided processing products are given in tables 10-I and 10-II for selected test fields.

The accuracies of the areal measurement of water bodies and salt marsh areas were high, based on the unsupervised clustering analyses of ERTS-1 CCT data. By counting subject picture elements and portions of boundary picture elements identified from the unsupervised clustering products, the areal extent of three salt marsh areas and 19 water bodies was determined from the ERTS-1 data. Comparison of the areal extent of these areas as obtained from the aircraft photography showed that (1) the accuracy of salt marsh areal measurements ranged from 89 to 99.8 percent, and (2) the error in estimating water body size was 2 hectares and was uncorrelated with the size of the water body.

When the spectral uniqueness of coastal features in the ERTS-1 spectral bands was evaluated, the Level I and II features were found to be represented by families of spectral reflectance curves. In the case of water, swamp, marsh, nonvegetated wetland, sand, dry grassland, and forest, there were separate and continuous families of spectral reflectance signatures or curves for each feature

TABLE 10-I.- OVERALL CLASSIFICATION ACCURACY OF ISOCLS FOR ALL STUDY SITES AND ALL DATES

Test Field	Water	Swamp	Marsh	Nonveg Wetland	Sand	Veg	Other	% Correct	
								Level I	Level II
Water	2972	0	0	0	0	0	0	100.0	-
Swamp	10	277	215	3	0	0	109	80.1	45.1
Marsh	34	104	1233	2	1	2	457	72.9	67.3
Vegetation	0	0	22	0	0	489	7	95.8	94.4
Other	1	3	16	12	24	31	906	96.8	91.2
					Overall Average			89.1	74.5

TABLE 10-II.- OVERALL CLASSIFICATION ACCURACY OF LARSYS FOR ALL STUDY SITES AND ALL DATES

Test Field	Water	Swamp	Marsh	Nonveg Wetland	Sand	Veg	Other	Threshold	% Correct	
									Level I	Level II
Water	912	6	80	0	0	0	0	30	88.1	-
Swamp	0	298	68	0	1	0	18	27	88.8	72.3
Marsh	10	22	628	2	10	0	53	111	78.0	75.1
Nonvegetated Wetland	0	0	0	134	26	0	0	13	77.5	77.5
Vegetation	3	0	0	7	10	148	4	22	83.5	76.3
Other	0	65	18	0	23	51	820	102	82.9	76.0
							Overall Average		83.2	75.4

type. Bright urban and sand signatures were intermixed. All Level-III features investigated, such as water turbidity zones, algal mats, salt marsh, pine, and hardwoods, were found to have unique and repeatable reflectance signatures, not grayscale signatures, for the three sets of ERTS-1 data considered (August 29, October 3, and November 26, 1972, data sets). These findings suggest that the use of a signature data bank should be explored to classify ERTS-1 data without the use of training fields.

The results of the evaluation suggest three potential applications of the ERTS-1 data to coastal survey problems.

1. Surface water bodies can be detected and their areal extents determined from ERTS-1 data.
2. ERTS-1 data should be used to map the coastal wetland areas of the State of Texas and other states as a management aid and to track trends in the reduction of wetland areas.
3. Turbidity patterns determined by the ERTS-1 data should be used in the verification and development of bay and estuarine circulation models now being developed by the U.S. Corps of Engineers and others.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas, November 2, 1973
641-14-07-50-72

11.0 REFERENCES

1. Shaw, S. P.; and Fredine, C. G.: Wetlands of the United States. Circular 39, USDI, Fish and Wildlife Service, Washington, D.C., 1956.

2. Dolan, R.; Godfrey, P. J.; and Odum, W. E.: Man's Impact on the Barrier Islands of North Carolina. American Scientist, vol. 61, no. 2, 1973, pp. 152-162.

3. Fisher, W. F.: Environmental Geologic Atlas, Texas Coastal Zone, Galveston-Houston Area. Bureau of Economic Geology, The University of Texas at Austin, 1972.

4. Chism, S. B.; and Hughes, C. L.: Screening and Data Handling Plan for ERTS-1 Computer Compatible Tape (CCT) and Aircraft 24-Band Scanner Data. LEC/HASD Report No. 640-TR-132, Houston Aerospace Systems Division, Lockheed Electronics Company, Inc., Houston, Texas, 1972.

APPENDIX A
FIELD SURVEY INFORMATION

This appendix presents the detailed field survey data that was collected and the related analyses to support the ERTS-1 coastal investigation.

1 DETERMINATION OF BOUNDARIES

The waning of the Pleistocene glaciers and the simultaneous rise in sea levels during the Holocene era brought dramatic changes to the Texas coastline. Large portions of the Trinity River and San Jacinto Valley were inundated, filled, and developed prograding deltaic systems which are still active. Simultaneously, Pleistocene sands were eroded, reworked, and deposited along the present-day coast, where barrier island systems have evolved. The recent sedimentary history and active processes have developed a complex set of depositional wetland environments. The boundaries between environments seldom appear as distinct lines, which is sometimes suggested by satellite imagery. Rather, boundaries normally occur in nature as ecological gradients between environments.

The following sections characterize wetland environments and boundaries between environments, and the dominant vegetal species which these environments contain.

Section 3.0 briefly described the natural features that the Coastal Analysis Team attempted to classify at Level I and Level II in the coastal feature hierarchy. Similarly, figures 5-4, 5-5, and 5-6 illustrate approximately a Level II

classification. In terms of natural environments, wetland corresponds to a transitional zone between water and various other types of dry land surfaces. In the Trinity Site, a regional ecological gradient corresponds to the trends of salinity and topography, whereas natural variations in the Galveston and Bolivar sites are controlled primarily by topographical changes. This basic difference, as well as geomorphic differences between sites, results in examples of both physiographically complex (Trinity) and simple natural (Galveston and Bolivar) situations.

Natural Transition From Tree-Covered Surfaces to Grass-Covered Surfaces

The Pleistocene rivers cut through the then existing sedimentary surface to a base level about 137 meters (450 ft) below present sea level. Remnants of that surface in the Trinity River study site typically occur as mixed pine and deciduous forest on well-drained sand and clay (figures A-1, A-2, and A-3). Frequently, manmade openings in the forest cover are used for pasture, but are seldom cropped.

Moving from the Pleistocene surface to the Holocene surface corresponds to a decrease in elevation of from 2 to 3 meters, an increase in soil moisture and standing water, and a change from semiconsolidated to unconsolidated sediments. The boundary between these two environments represents perhaps the sharpest natural boundary and is the result of the Trinity River cutting into the Pleistocene sediments. Figure A-4 shows a boundary occurring between a mixed pine and deciduous forest (D) and a swamp (S). Swamp typically consists of a variety of water-tolerant hardwoods and

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28208

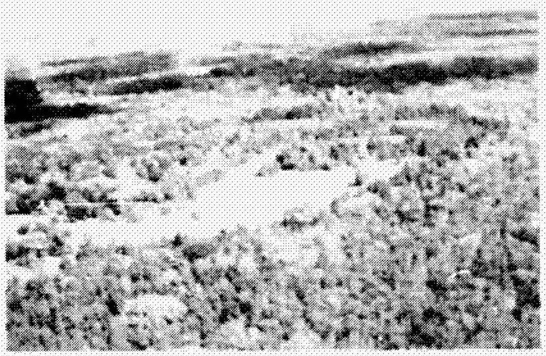


Figure A-1.- Mixed deciduous and pine forest on Pleistocene surface adjoining Trinity River alluvial valley.

Figure A-2.- Closeup of deciduous and pine forest canopy.

Figure A-3.- Ground photograph of deciduous maple trees bordering an open field.

associated fluvial woodland vegetation (figures A-5 and A-6). An intermediate terrace, partially covered with swamp vegetation, apparently exists at some points between the Pleistocene surface and the Holocene surface and is intermittently inundated. The terrace is shown topographically on maps, and occasionally induces a spectral response which differs from surrounding background. Figures A-5 and A-6 show a low-altitude aerial photograph of dense and sparse swamp vegetation cover.

In the upper portions of the Trinity study site, the swamp and fluvial woodland vegetation extends across the full width of the Holocene surface. Moving upstream there is a gradual transition from the more water-tolerant tree species to less water-tolerant species. Moving downstream, there is a gradual transition to marsh; however, trees continue to occur along the higher portions of natural and manmade levees and along spoil banks.

Figure A-7 shows the Trinity River bordered on one side by swamp and on the other side by a sparse cover of willow trees. The L_2 is at a lower elevation than L_1. No trees or other woody vegetation occurred beyond the L_2 tree line. If water levels had been lower at the time of photography, the gradual change from trees to marsh grasses would appear. The dense tree stand on the far side of the river indicates higher and slightly drier edaphic conditions than the levee on the near side of the river. Similarly, but at a smaller photographic scale, an overview of the transition from the Pleistocene surface of mixed pine and deciduous forest (P) to the Holocene grass-covered surface (G) is shown in figure figure A-8. In the foreground, willow trees (W), along with other water-tolerant tree species, occupy the narrow bank along the Trinity River.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28206

Figure A-4.— Transition fro deciduous forest (D) to swamp (S) to the Trinity River (T).

Figure A-5.— Inundated swamp along the Trinity River.

Figure A-6.— Sparse distribution of woody vegetation in a transition zone between swamp and the river system.

Large portions of the Pleistocene surface are cultivated. The transition from tree-covered to grass-covered surfaces resulted in marked spectral differences, with less obvious spectral differences occurring between grass-covered natural environments and grass-covered man-induced environments, such as pasture or rice agricultural surfaces (figure A-9).

Transition From Grass To Water

Although swamp and other tree vegetation form important ecological units in the study areas, these are limited geographically to small portions of the Trinity River Study Site. Herbaceous vegetation of marsh wetlands, consisting of a variety of grasses, sedges, and rushes, form the most prominant wetland ecological unit in the study areas considered. Geographically, marsh wetlands are located on the lower portions of the Trinity River, the bayside of barrier islands (Galveston and Bolivar), and topographically low sites found inland. Figures 4-3 and 4-4 show the ecological relationships typical of the study sites and list the commonly encountered vegetation.

Figures A-10, A-11, and A-12 show an overview of the Trinity River delta. Deltaic systems characteristically demonstrate cyclic sedimentation, abandonment, subsidence, and rejuvenation. Figure A-10 shows a recently abandoned delta (ab) and an active (ac) prograding delta. The process of abandonment begins with a decrease in water discharge along a channel and a corresponding decrease in channel sedimentation. Figure A-11 illustrates that as channel depth decreases, subaqueous vegetation establishes itself and is eventually replaced by water-tolerant emergent grasses (c)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28205

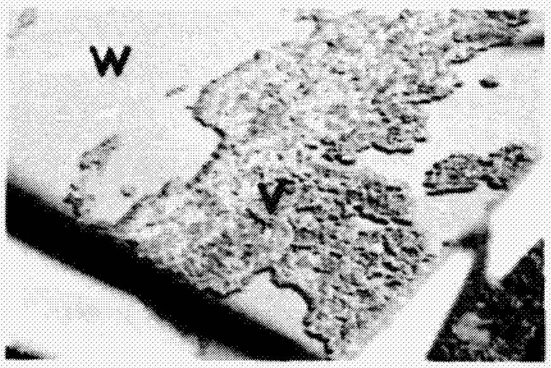


Figure A-7.— Ecological gradient from the Trinity River (T) to low-lying natural levee (L_2). The highest driest portions of the natural levee (L_1) also correspond to the coarsest-grained sediments.

NASA S-73-28204

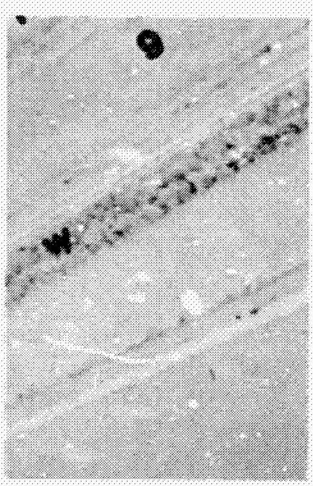


Figure A-8.— Transition from Pleistocene (p) to grass (g) on the lower elevation Holocene surface. Typically bordering the Trinity River are willow trees (w).

Figure A-9.— Agricultural fields found on the Pleistocene surface.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28209

Figure A-10.- Active (ac) and abandoned (ab) Trinity River delta systems.

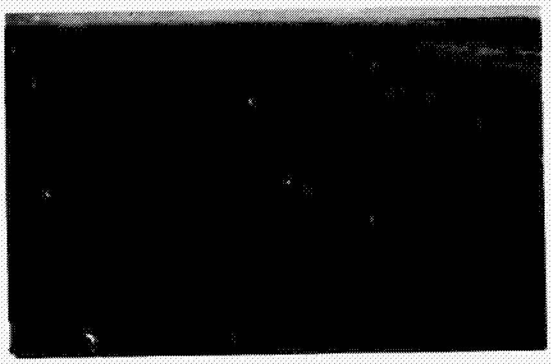


Figure A-11.- Channel abandonment shown by channel fill (c), natural levee (a), and inter-levee basin (b).

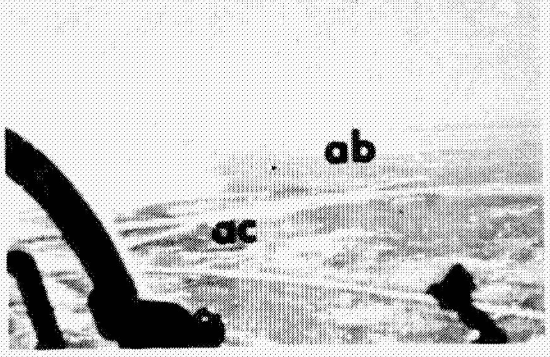


Figure A-12.- Upper portions of the Trinity River delta during inundated river phase. (Only natural levee sediments are exposed.)

A decrease in discharge reduces the amount of sediment reaching the natural levee (a) and interlevee (b) systems to insignificant levels. With regional or local subsidence, deltaic sediment masses become inundated and progress through a series of gradual vegetal changes. Salinity and topography strongly influence the typical vegetal succession. Normally, higher elevations are drier and less saline than lower elevations. During the sedimentation phase, deltaic terrain trends toward higher elevations, drier soil, and less saline ground water.

Similarly, sedimentation increases the elevation above ground water tables on the barrier island; however, ground water salinities often remain high because of proximity to the ocean, which restricts vegetation to salt-tolerant grass species. The mechanics of onshore wave action and sediments carried alongshore, respectively, provide the primary energy and sediment source for deposition and erosion on the beach side of the barrier. In contrast, sands and silts washed or blown across the island provide a small amount of bayside sedimentation.

The processes of sedimentation initiate vegetal growth, which in turn brings about further sedimentation and vegetal succession. In the deltaic environments of the Trinity River, initial vegetal groups (figures A-13 and A-14) include subaqueous and emergent hydrophytes, such as alligator weed, cordgrass, sea oxeye, roseau cane, bulrushes, and cattail. When salinities are higher, *Salicornia* spp., *Juncus* spp., and *Spartina* spp. are common. Less frequently inundated areas (figure A-15) have similar vegetation, but may also include

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28205

Figure A-13.- Roseau cane (*Phragmites communis*) in a matrix of alligator weed (*Alternanthera philoxeroides*).

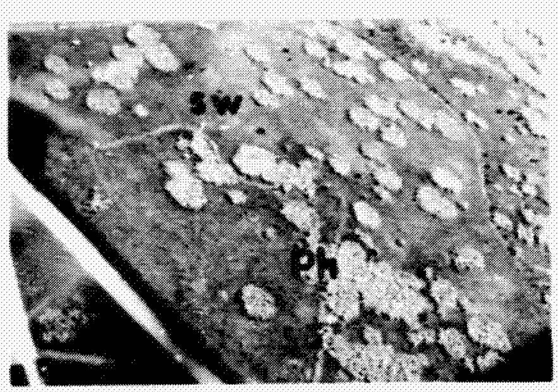


Figure A-14.- Undifferentiated floating and emergent hydrophytes.

NASA S-73-28204

Figure A-15.- Undifferentiated emergent hydrophytes.

Baccharis spp., marsh elder, small willow trees, and several other brackish to fresh water grasses. Figures A-16, A-17, and A-18 illustrate ground views of typical *Spartina alterniflora* marsh sites in the study.

The difference in color and "texture" between figures A-16 and A-18 corresponds to new spring growth and winter mature grasses, respectively. The differences in color within figure A-18 correspond to high vigor *Spartina alterniflora* (dark brown) growing in saline water or saturated soils and low vigor grasses of the same species (light brown) growing on a drier soil. These areas represent low physiographic and vegetal diversity and relatively undisturbed situations.

Shorelines facing the predominant southeasterly wind along the Texas coastline provide examples of less-protected marsh. Figures A-19 through A-24 show examples of the effect of slight changes in elevation on vegetation. Topographically low frequently-inundated areas may or may not be occupied by vegetation. Figure A-20 shows a non-vegetated tidal flat (c) where, as shown in figures A-19, A-20, and A-21, areas of nearly equal elevation are covered by aquatics (A) such as *Salicornia* spp. and a green algal flexible mat incorporating about an inch-thick sand layer. Green algae, when found, often occurs in a partially protected area, such as a wet swale between two beach edges. The most common transition encountered in the field sites was a succession (figure A-21) from green algal mat whose filaments hold sand grains (A) partially protected from wave action or nonvegetated sediment often not protected through *Salicornia* spp. (B), *Distichlis* spp. (C), *Spartina patens* and *Spartina alterniflora*, and *Baccharis* spp. (A) (figure A-24)

NASA S-73-28203

Figure A-16.- Spring growth of *Spartina alterniflora* marsh.

Figure A-17.- Mixture of spring growth and winter growth of *Spartina alterniflora* on Galveston Island.

Figure A-18.- Winter growth of *Spartina alterniflora*. Dark brown located in inundated area, light brown is located on higher drier soil.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28202

Figure A-19.- Transition from water through *Salicornia* spp. (A) and *Distichlis spicata* (B).

Figure A-20.- Tidal zone showing *Salicornia* spp. (a) *Distichlis spicata* (b), *Spartina alterniflora* (c), nonvegetated tidal flat (e).

Figure A-21.- Transition from green algal mat (A) through *Salicornia* spp. (B). *Distichlis spicata* (C), and *Spartina* spp. (D) looking south from Bolivar's sand tip northeast of the jetty.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28201

Figure A-22.- Salt marsh environments; salt flat grass *(Monanthochloe litloralis)* (a), *Salicornia* spp. (c), and *Spartina alterniflora* (b).

Figure A-23.- Ancient ridge and swale topography on Galveston Island.

Figure A-24.- Salt marsh environments; high dry marsh (A) to open water (D). *Braccharis* spp. (A), *Distichlis spicata* (B), *Juncus roemerianus* (C), and open marsh pond (D).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

and other shrubs on the highest, driest parts of the marsh.

Farther inland, it is not uncommon to find swales between old beach ridges which may or may not dip below ground water levels (figure A-23) and which become basins for local runoff and an ecological niche for the growth of a variety of aquatic plants. Cattail, bulrush, and sloughgrass commonly inhabit the wet lowland nonmarine portions of the barrier islands.

Spartina patens and *Spartina spartinae* (figures A-25 and A-26) are among the two most common grasses inhabiting the highest, driest portion of the barrier. In addition, various shrubs and weeds, such as rattlebox, bluestem grass, *Baccharis* (figure A-27), mesquite, and some trees may be found. Because of intensive pasturing and selective grazing by cattle (figure A-26), the pattern of grasses no longer necessarily reflects natural distributions. Grasses, shrubs, and weeds outside known wetland areas therefore were not closely observed and were considered to be undifferentiated barrier flat vegetation. Closeup photographs of the various vegetal species are shown in figures A-28 through A-34.

Each change in vegetal type indicates a change in edaphic conditions and also normally corresponds with changes in spectral reflectance; this is shown in figure A-21. Where the change is spatially systematic, such as a rising elevation on a ridge, spectral signatures may be related to several of these systematic changes. However, in large areas of marshland systematic changes are less obvious (figure A-24) and result in vegetal heterogeneity. Relating satellite remotely sensed features to edaphic conditions in the marsh is therefore speculative.

NASA S-73-28200

Figure A-25.- General view of *Spartina patens* marsh.

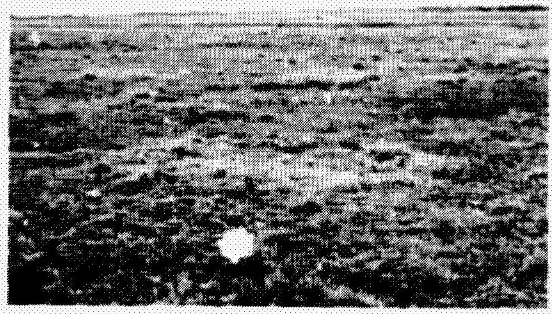


Figure A-26.- General view of a mixed *Spartina patens* and *Spartina spartinae* pasture.

Figure A-27.- General view of *Baccharis* spp. shrub cover.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28197

Figure A-28.- *Spartina patens*.

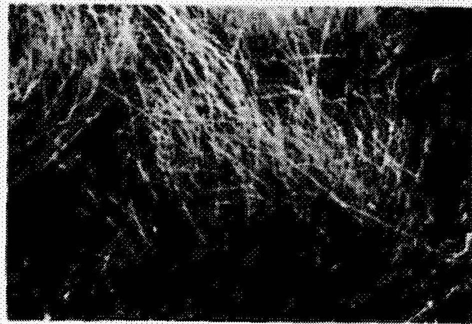


Figure A-29.- *Spartina spartinae*.

Figure A-30.- *Baccharis* spp.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28211

Figure A-31.- *Salicornia* spp.

Figure A-32.- *Distichlis spicata*.

Figure A-33.- *Spartina alterniflora*.

Figure A-34.- *Juncus roemerianus*.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

Adequate study and knowledge of any particular site's vegetation assemblage and relationship to recent geologic history was not accomplished at the time this report was written. This lack of adequate study necessarily lessened the effectiveness of this report.

Transition From Surf Zone to Dune Line

The transition from the near-shore surf zone to the dune line behind the beach represents one of the few examples of nonvegetated wetland in the study areas. This transition also represents the incipient geomorphic formation of the barrier island feature.

Part of the energy consumed by a water wave approaching a beach lifts and transports sediment, shells, and manmade trash. As waves break along the beach front, energy levels rapidly decrease and the transported material is deposited (figure A-35). At the same time water rushes up the beach slope to a point where its velocity reaches zero. A portion of the water runs down the slope and the remainder filtrates through the sand to the ground-water table. Various sediment and slope characteristics determine the downward rate of water movement. Water is stored in the grains of the sediment; the surface tension of water tends to stabilize the sediment, while the water coating the sand grains tends to cause a darker hue.

As the tide moves in and out, the strand line, which is the line of shell, coarse sediment, and trash, typically moves correspondingly. On the outgoing tide the sand remains wet for a period far landward of the strand

(figure A-36). Furthermore, osmotic pressures force some ground water toward the surface, which maintains a slightly darker hue in the sand.

As the sand dries, onshore sand tends to move under the force of the more dominant onshore winds, first as sand ripples, and eventually as waves or dunes. Since wind velocities seldom reach levels where coarse material such as shell can be moved, a rough surface develops which consists primarily of residual materials (figure A-37). Furthermore, the windblown sands dry rapidly and take on a lighter color.

Landward of the rough surface of residual materials in the study area, dunes become relatively quickly stabilized by plants such as beach morning glory and sea oats (figure A-39). Sands continue to deposit on the windward side of the dune and move slowly toward the bay side of the barrier. Dense stands of salt-tolerant grasses behind the dunes (figures A-39 and A-40) impede horizontal movements, cause deposition, and raise elevations to set the stage for various kinds of barrier island vegetation. Although windblown sediments reach the bay side of the barrier in small quantities, storm-driven water washing over the barrier provides the dominant means of sediment transport toward the bay. This is particularly true along the narrow portions of the island.

Marine sediments moving across the barrier merge with the bay side to form relatively well-protected marshlands. The continual influx of sediments to the estuary from mainland sources and marine sources results in estuary shoaling and eventual filling.

NASA S-73-28198

Figure A-35.— Beach berm and strand line.

Figure A-36.— Intertidal zone.

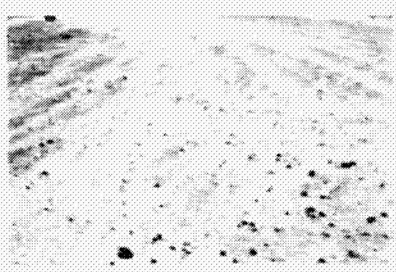


Figure A-37.— Deflation zone (residual sands and shell).

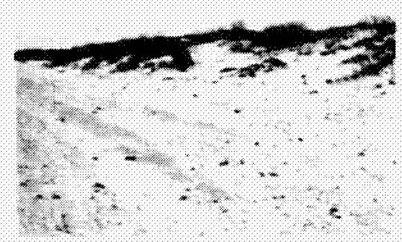


Figure A-38.— Dune zone.

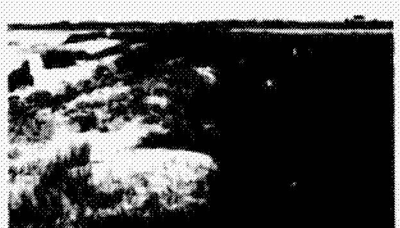


Figure A-39.— Salt marsh flat.

Figure A-40.— Salt marsh flat.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

In some areas, such as where the beaches adjoin the jetties, especially the north jetty, large quantities of sediment are deposited. The sedimentation rates exceeding the rates of marine or eolian erosion result in a seaward progradation of the shoreline. A feature of alternating topographic highs (ridges) and lows (swales) develops.

Typically, the swales are devoid of vegetation (figure A-41 and A-42), or, in protected areas, are covered by a green algal mat (A in figure A-43). Newly developed ridges often lack vegetation and are roughly equal in width to the swales (figure A-41); however, as the ridge builds upward, vegetation such as *Distichlis spicata* and *Salicornia* spp. take root and partially stabilize parts of the ridge. Because less stable parts of the ridge are easily moved by winds and tidal floods, the ridges eventually become narrower and steeper (figure A-42). During a high-tide phase, the ridges appear as linear islands separated by shallow linear water bodies. The lines tend to coalesce at some point into a ridge which may be part of another system of ridges and swales farther inland. The product of a prograding shoreline condition (cheniers) is then a ridge-and-swale topography of older age toward the bay side (see figure A-42). Figure A-43 illustrates a well-developed old swale on Bolivar Peninsula.

Water Types

Three properties of water bodies strongly influence their spectral nature in the ERTS-1 multispectral bands: surface roughness, surface debris, and materials held in suspension. The first two are usually not spatially significant; however, turbidity has a pronounced effect in the

Figure A-41.– Incipient ridge and swale topography. The foreground line tracks going away from the camera are in an incipient swale; the curved tire tracks (left edge) are on an incipient ridge.

Figure A-42.– Initial stages of ridge stabilization, Bolivar Peninsula.

Figure A-43.– Algal mat in a protected wet swale, Bolivar Peninsula.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

spectral and spatial domains in ERTS-1 data. In addition, reflection from shallow bottoms can cause changes in apparent water reflectance.

Figure A-44 shows one spectral effect at the north jetty at the mouth of Galveston Bay. The gulf side of the jetty is exposed to a mild onshore wind, which disturbs the surface. In contrast, the protected side of the jetty is relatively undisturbed and reflects skylight in a manner quite unlike the gulf waters. Similarly, the surf zone (figure A-35) and white caps (figure A-45) produce a pronounced spectral difference from smooth water surfaces.

Floating debris and plants on the water's surface, although uncommon in large quantities in the open gulf or bays (figure A-45), may be spectrally significant in inland lakes, rivers, and ponds. Floating and emergent hydrophytic plants commonly collect in undisturbed inland water bodies during the latter part of the summer. At other times of the year, floating debris is rarely sensed remotely.

The most important water property which is sensed remotely is water turbidity. Large quantities of suspended material produce obvious spectral differences, such as may be seen in figures A-45 and A-46.

NASA S-73-28210

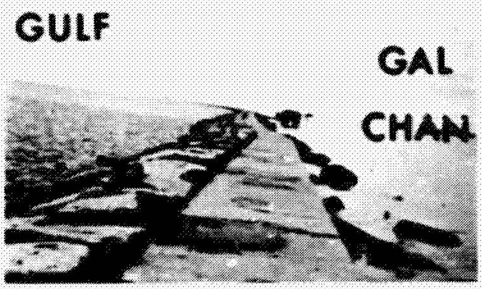


Figure A-44.- Surface roughness effects on water reflectance (north jetty looking southwest).

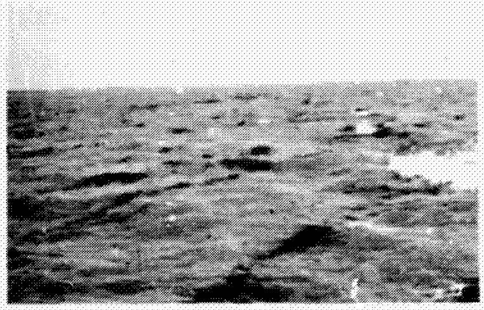


Figure A-45.- Debris in recent flood waters of the Trinity River.

Figure A-46.- Foam.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

WATER PROPERTIES SURVEY DATA

Each coastal study site consisted of 50 percent or more water. In the Trinity Site, the water bodies included the upper portions of Trinity Bay, Lake Anahuac, and several small island freshwater lakes. Unlike the freshwater or nearly freshwater bodies in the Trinity Site, the Galveston and Bolivar Sites were characterized by brackish and saline waters of the lower Galveston Bay, West and East Bays, and the Gulf of Mexico. In each case, extreme variability occurred in circulation and mixing dynamics. This variability was often sensed remotely as a result of spectral differences, which occur in the various water masses in the study area.

Numerous types of inorganic and organic materials introduced to the estuary and the Gulf by streams and other forms of natural and man-controlled runoff induce highly turbid water conditions. Fine-grained suspended inorganic material constitutes the primary turbidity factor affecting spectral reflectance; however, if chlorophyll and various other organic materials are present, these may affect the spectral reflectance. As a result of known effects, the measurements in the Galveston Bay, Trinity Bay, and the Gulf of Mexico included both turbidity and chlorophyll measurements. In addition, simultaneous temperature, salinity, and dissolved oxygen measurements were collected as auxiliary data.

Figures A-47 through A-50 illustrate the boat transects sampled throughout the Galveston Bay complex on 4 days. The January 19, 1972, transects covered the Galveston Bay plume, where the jetties direct estuarine water into the

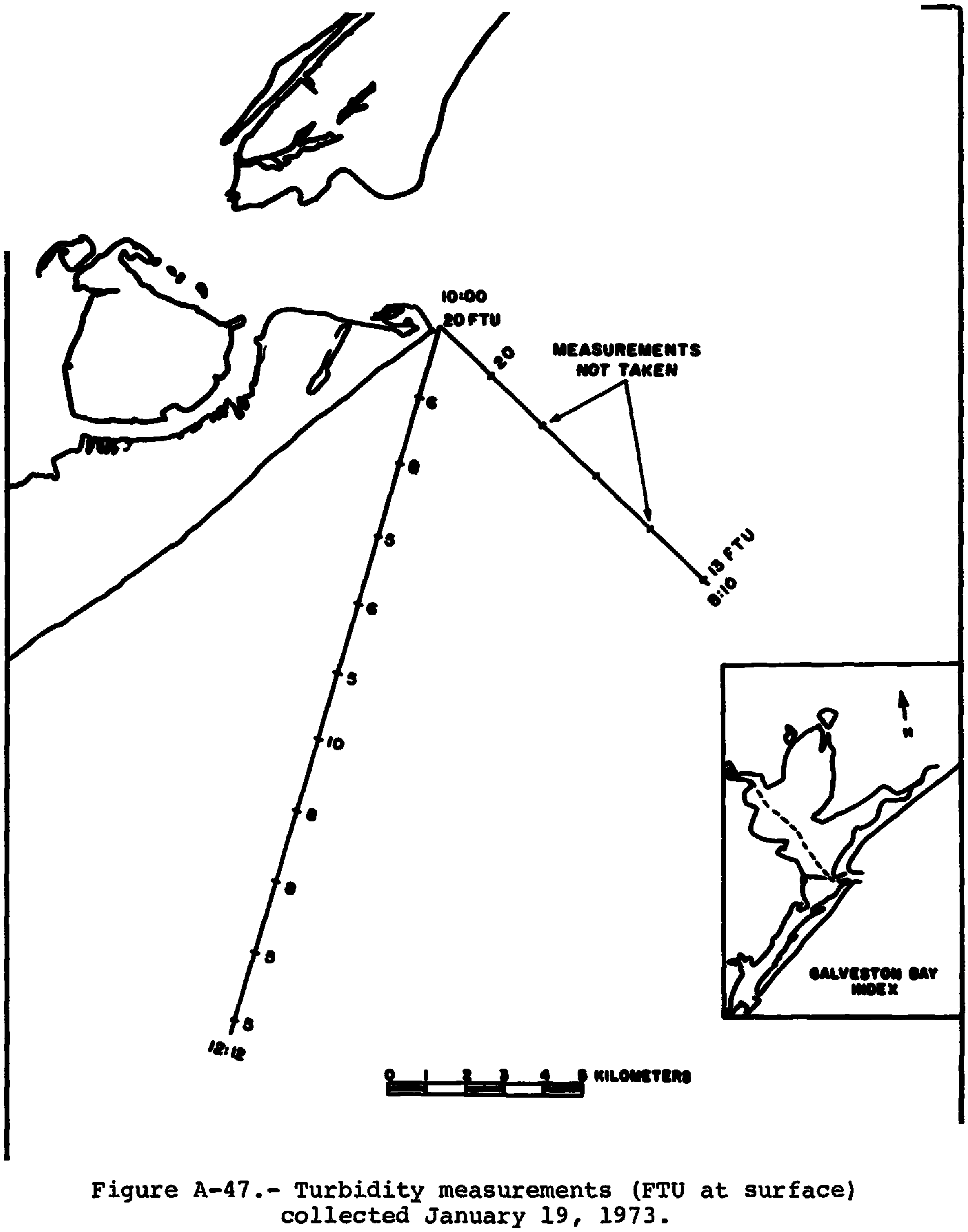


Figure A-47.- Turbidity measurements (FTU at surface) collected January 19, 1973.

NASA S-73-28212

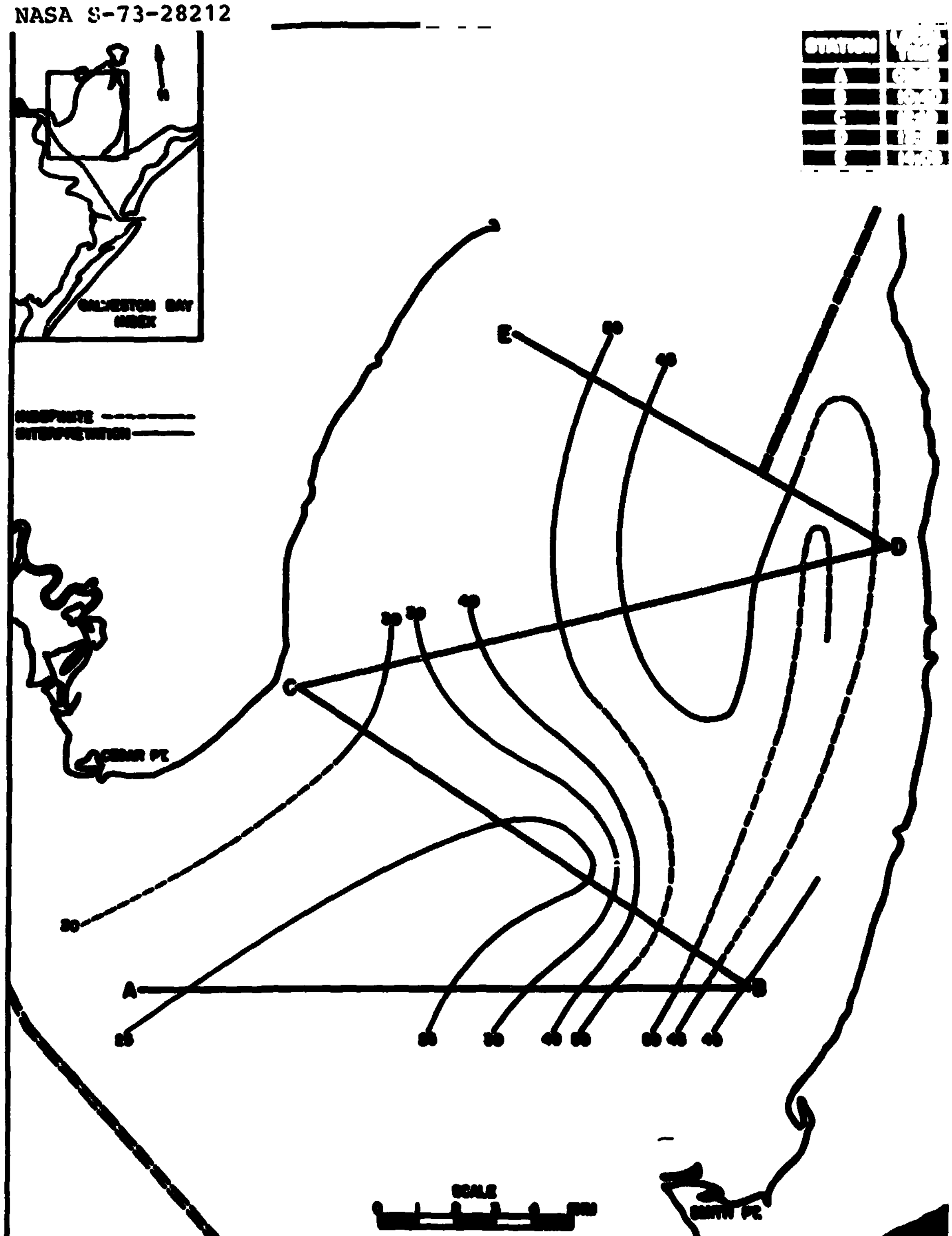


Figure A-48.- Turbidity isolines (FTU at surface) collected April 2, 1973.

NASA S-73-31458

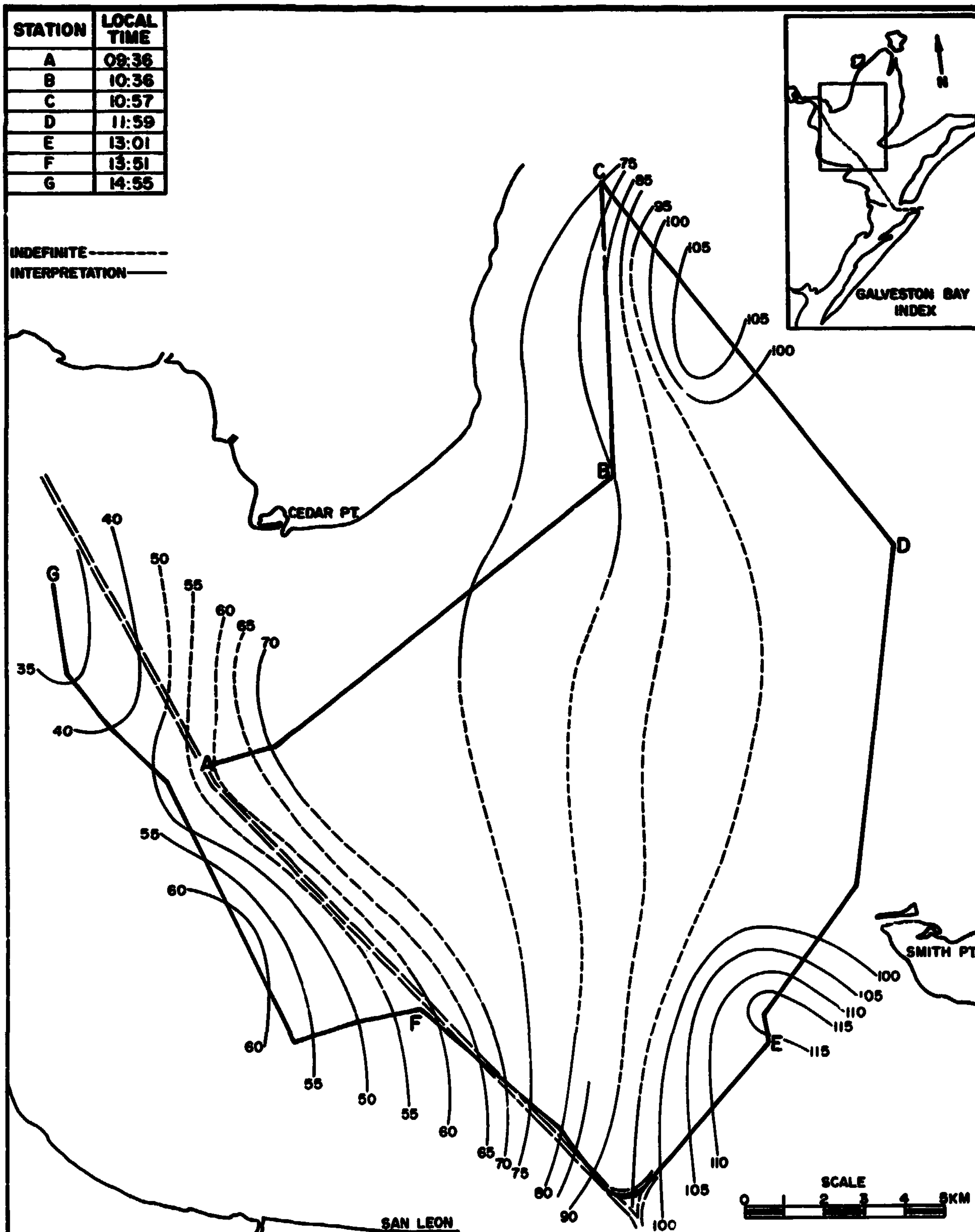


Figure A-49.- Turbidity measurements collected April 10, 1973.

NASA S-73-28213

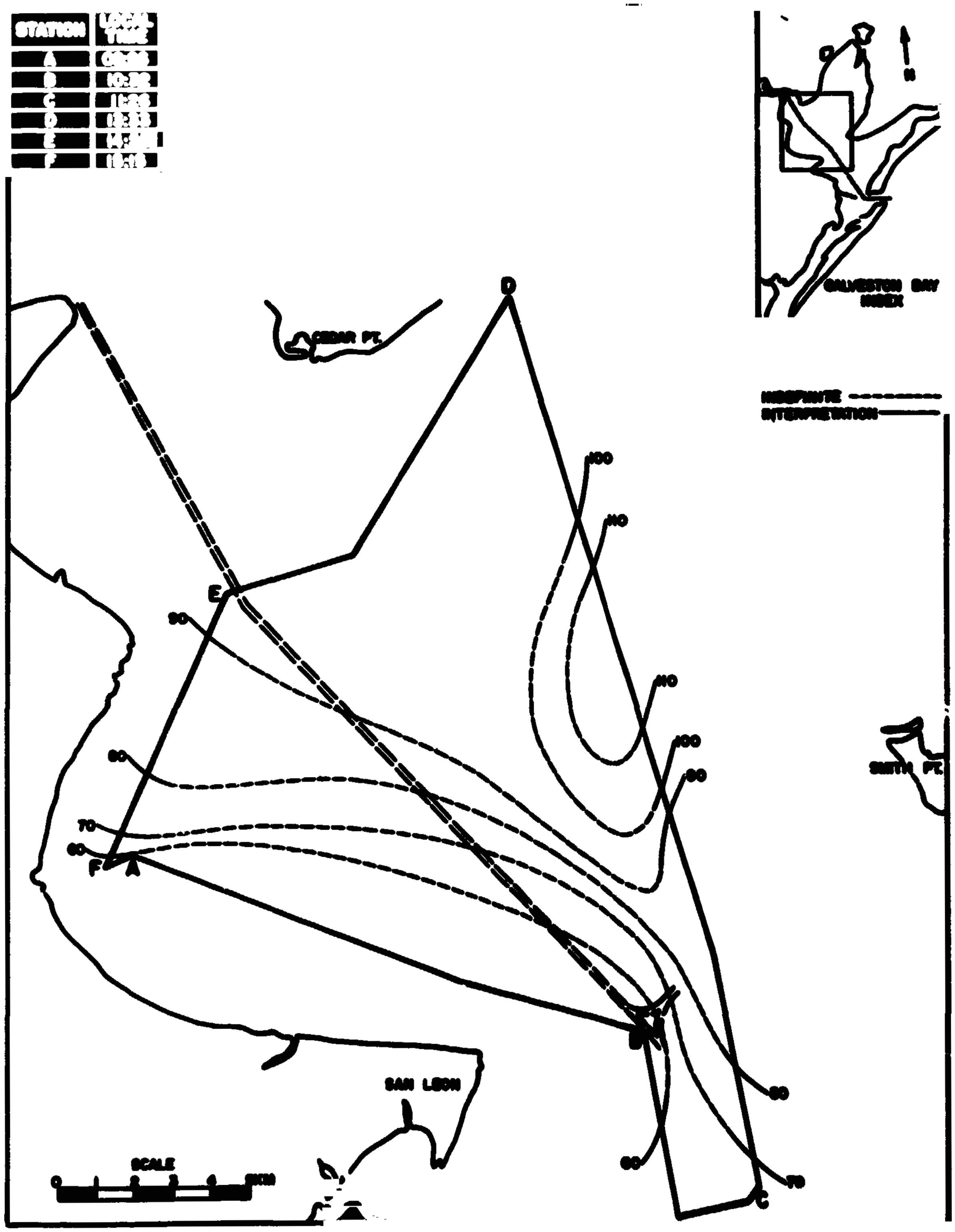


Figure A-50.– Turbidity measurements collected May 8, 1973.

Gulf of Mexico. The other three surveys covered the upper portions of Trinity Bay, Galveston Bay west of the Houston Ship channel, and the lower portions of Trinity Bay where East Bay waters mix with Trinity Bay waters.

Identical data were collected in each survey. Alignment of transects orthogonal to prevailing turbidity gradients was attempted in most cases with stations along each transect positioned 1.8 kilometers (1.0 n. mi.) apart. In this manner measurement of surface turbidities for that day cover the maximum range of turbidities.

Turbidity

Three general factors influence the spectral nature of turbidity levels sensed at the detector in the satellite. These include the interaction of the following:

a. Incoming solar radiation and the atmosphere

b. Solar radiation and water

c. The upwelling reflected solar radiation and the atmosphere

The field program attempted to describe empirically the nature of the interaction of solar radiation and water in the study sites. Measurements were made of the interaction of incoming radiation and the atmosphere to determine the magnitude of these factors and their eventual detailed assessment.

Four types of turbidity measurements were considered. Two of these measurements were turbidity estimate concentrations of suspended material near the water's surface, and the remaining two measurements estimated the corresponding spectral effects at those sediment densities. As ancillary data for adjusting the effects of solar zenith angle and atmospheric thickness, interim solar angle measurements and cloud cover estimates were collected.

Incoming solar radiation. Direct measurement of incoming solar radiation was made by an EXOTECH four-channel spectrophotometer (figure A-51). The spectrophotometer was used to collect this and upwelling data from the water's surface. Each channel (figures A-52 through A-55) corresponds in bandwidth response to the four ERTS-1 multispectral scanner channels. Incoming radiation being reflected by the water is a function of this measurement.

Field measurements of solar radiation included one reading for each spectral band taken a minimum of four times each day. Figure A-56 shows April 2, 1973, April 10, 1973, and May 8, 1973, data. The data for April 10, 1973, and May 8, 1973, typify cloudless days. The apparent difference in signature between the 2 days may be attributed to a slight but obvious brown haze which induced an attenuation in incoming solar radiation. The April 2, 1973, data collected on a cloudy day result at times in an even more pronounced attenuation of and variations in the instrument response to incoming radiation. When atmospheric haze was at a minimum, instrument readings equaled those of the April 10, 1973, clear day readings; conversely, when haze was greatest, instrument readings were less than on May 8, 1973.

NASA S-73-28207

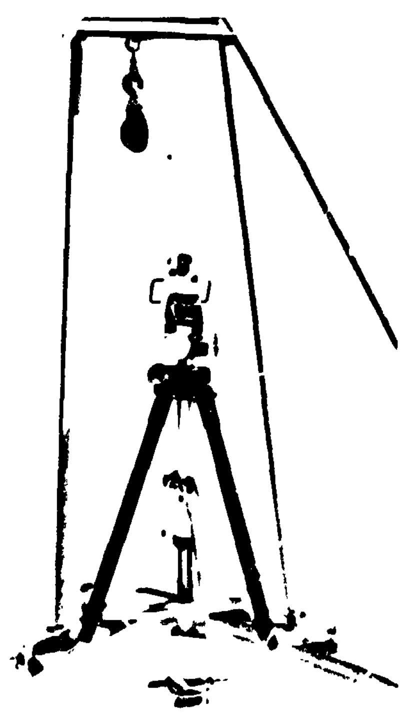


Figure A-51.- EXOTECH radiometer mounted on bow of research vessel.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

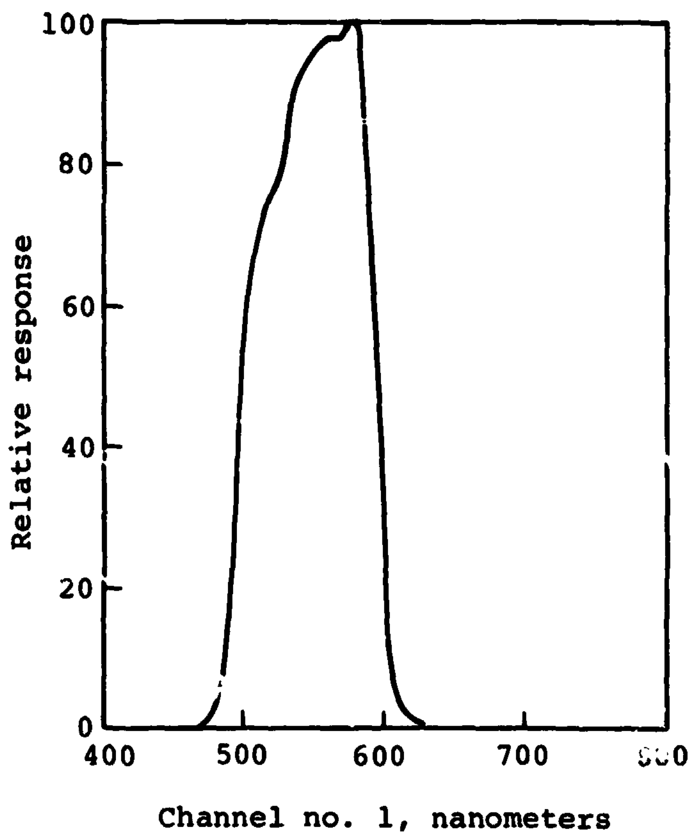


Figure A-52.— Bandpass function of EXOTECH channel 1.

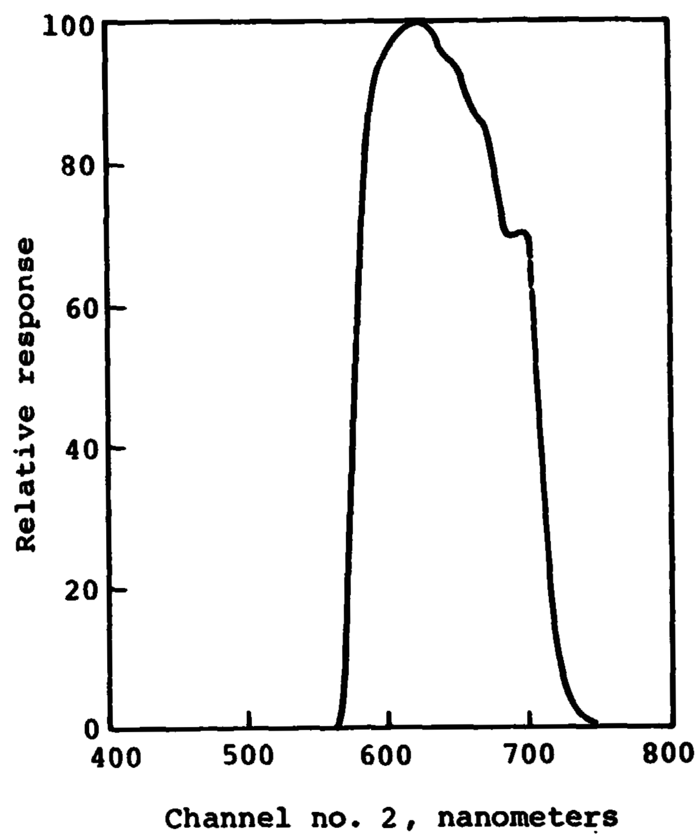


Figure A-53.— Bandpass function of EXOTECH channel 2.

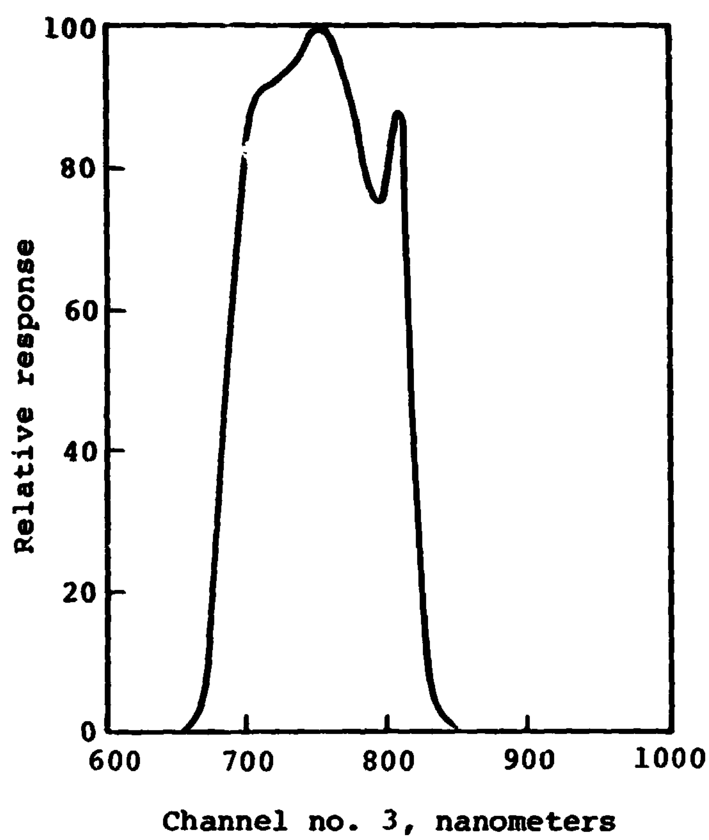


Figure A-54.– Bandpass function of EXOTECH channel 3.

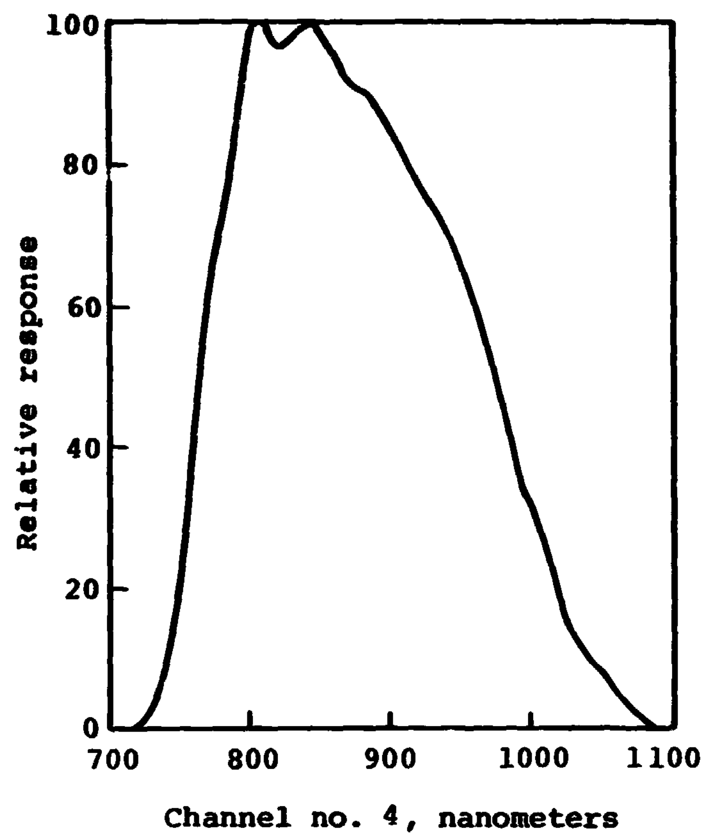


Figure A-55.– Bandpass function of EXOTECH channel 4.

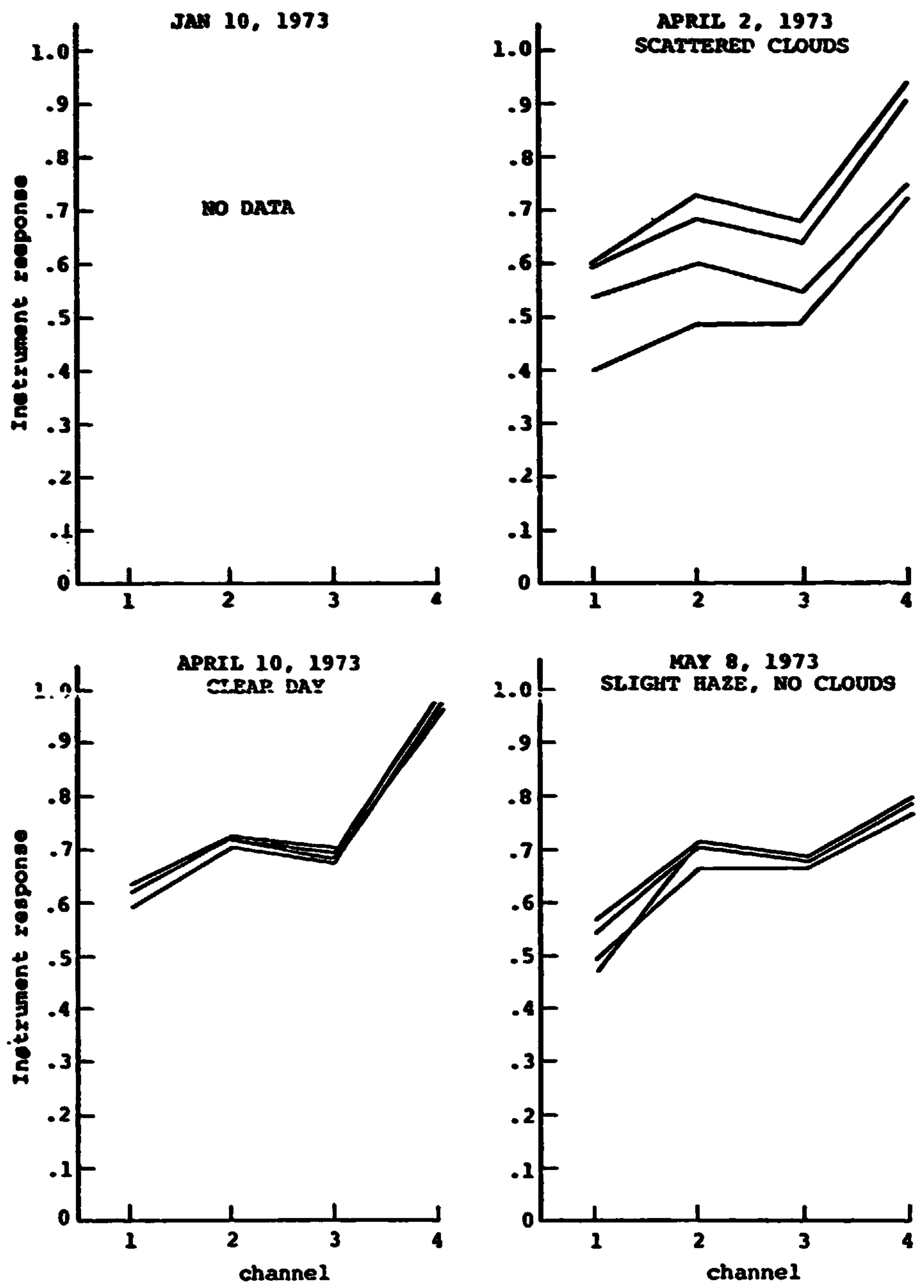


Figure A-56. - Instrument response to direct solar radiation.

The field data suggested a dependence of upwelling radiation on the angular effects of incoming solar radiation. That dependence, however, becomes nearly insignificant at low solar zenith angles. During the late morning and early noon hours, solar angle produces almost no variation in the radiometric measurements. Figures A-57 and A-58 show the plot of instrument response to direct solar radiation as a function of solar zenith angle. The horizontal line represents the mean value on each day for these measurements. With the exception of the April 2, 1973, cloudy-day data, the consistency of instrument response through all angles was apparent. The differences in atmospheric attenuation between the clear-day measurements and most cloudy-day measurements resulted in a lowering of solar radiation of about 25 percent in each spectral band. Although atmospheric attenuation was not considered in detail in subsequent analyses, the significant effect it may have on the deduction of water properties is recognized.

Interaction of solar radiation and water. In contrast with direct solar radiation measurements, where a diffusing lens averages incoming radiation, upwelling radiation data were collected with a 15° field-of-view lens. Because of this difference, the instrument response to incoming and upwelling light was not comparable with their present form. This section considers the upwelling solar radiation from waters within the study areas.

Turbidity measurements were made aboard the Texas A&M vessel *Excellence*. A flow-through pump allowed surface sampling within about 0.3 meter of the surface, as well as

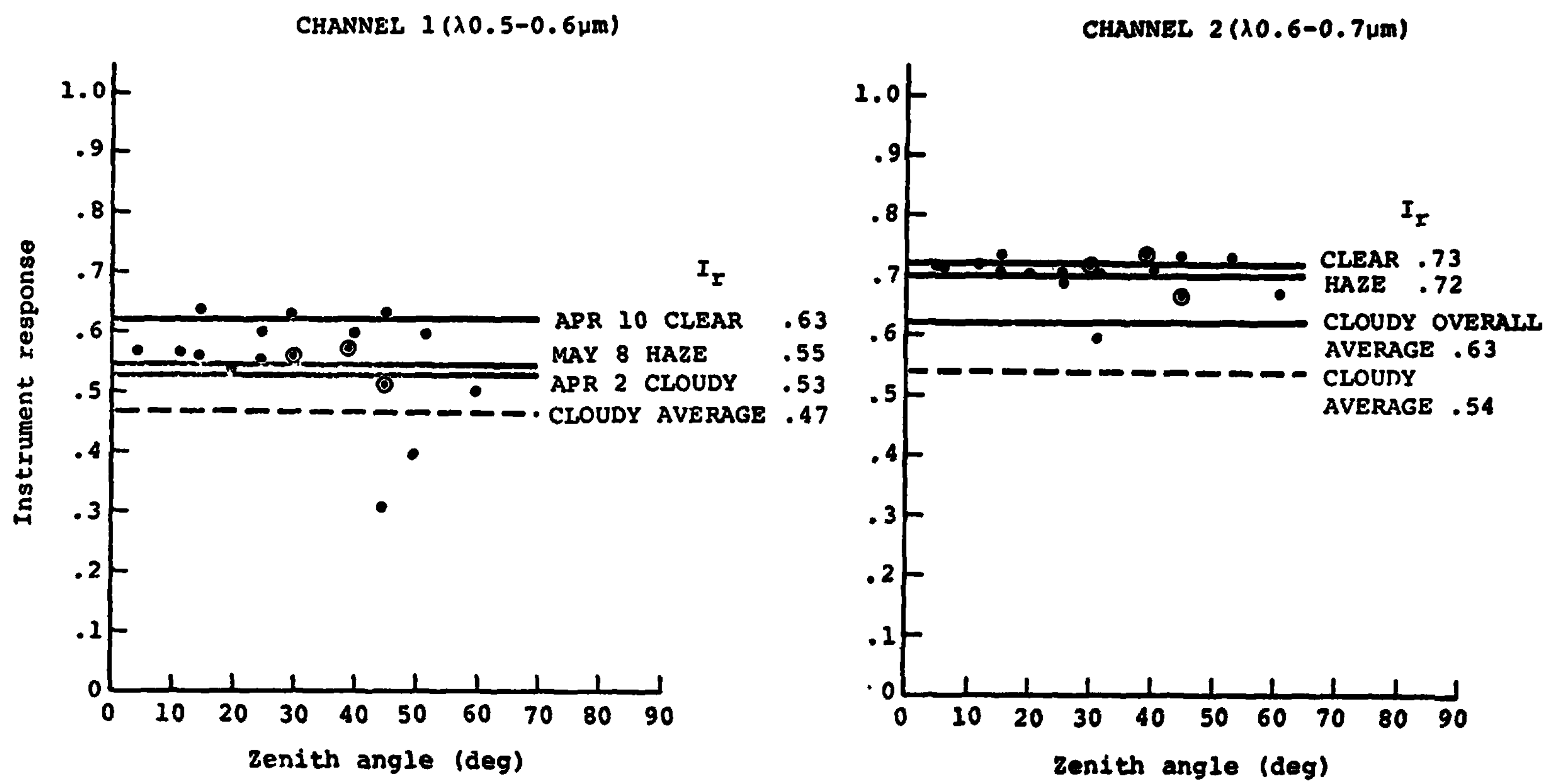


Figure A-57. - Instrument response to direct solar radiation as a function of solar zenith angle, channels 1 and 2.

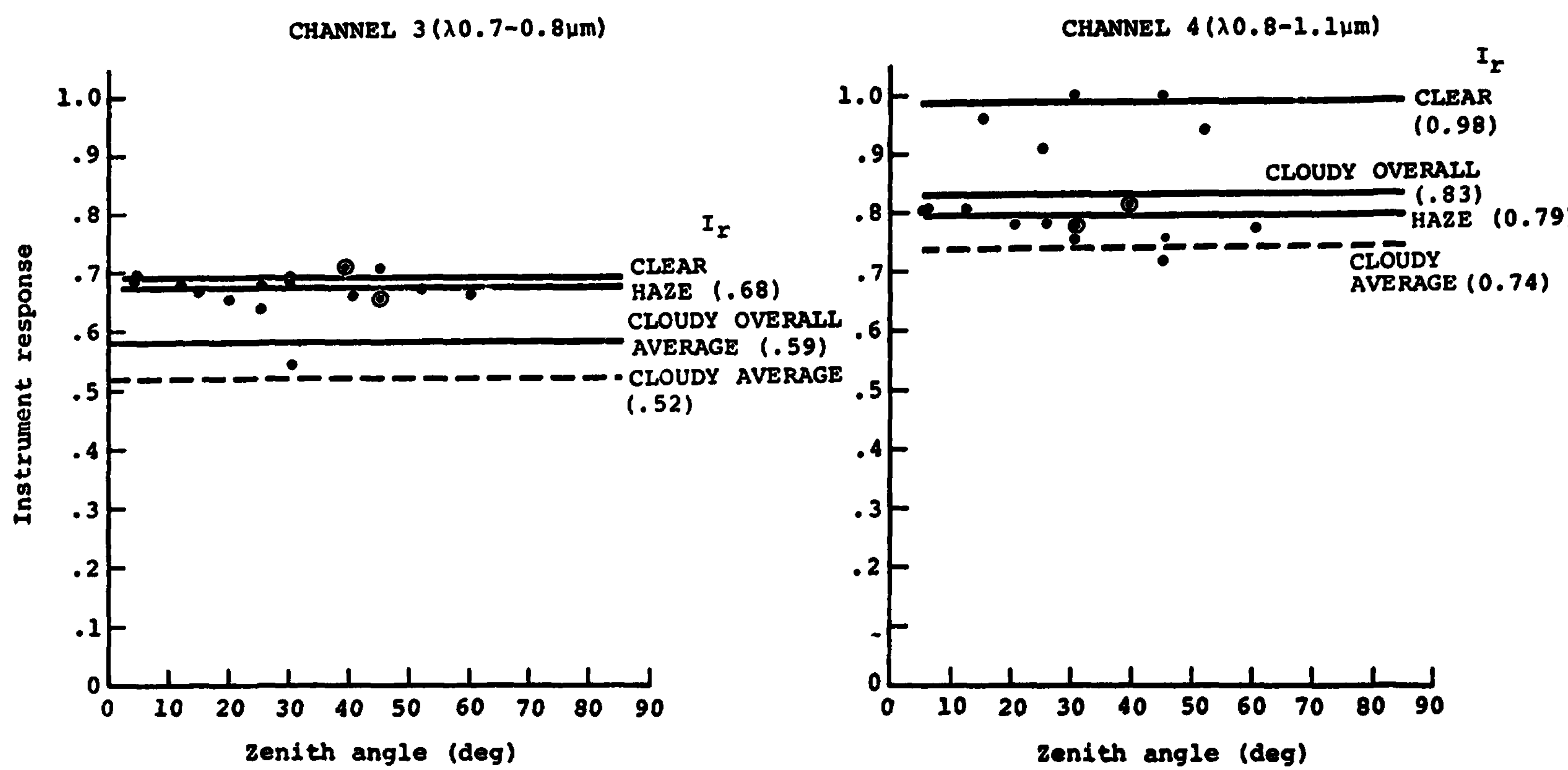


Figure A-58.- Instrument response to direct solar radiation as a function of solar zenith angle, channels 3 and 4.

sampling at different depths. A HACH turbidometer was used to analyze water samples. The turbidometer measures in units that are equivalent to milligrams of silica per liter aqueous solution or ppm by mass (equivalent SiO_2), and is accurate to ±1 ppm. Turbidity measurements were taken at the surface every 1.8 kilometers to a depth of 0.9 meter for the Galveston plume transect (figure A-47 on January 19, 1973). Surface measurements were taken every 1.8 kilometers (1 mile) for the water tracks (figures A-48, A-49, and A-50) on April 2, April 10, and May 8, 1973.

Similarly, Secchi disk readings provided a rough measure of the transmissivity of upwelling light and corresponded to the depth at which the disk disappears from the observer's view. Figure A-59 illustrates the relationship between Secchi disk readings and turbidity in Galveston Bay. Although the expected inverse relationship occurred, the spread of points about a best-fit line was large (linear correlation coefficient $r = 0.73$). No doubt observer subjectivity explains many of the measurement variations. These variations indicated to the investigators that only HACH turbidometer measurements would be considered in subsequent analyses.

The peak transmittance of solar radiation in distilled water and very clear ocean water occurs between wavelengths of 400 and 500 nm. Peak transmittance shifts toward the 500- to 600-nm band as suspended sediment concentrations increase, and may exceed those wavelengths at extremely high turbidities or under other surface conditions. The total quantity of light decreases simultaneously, reaching extinction at some critical depth.

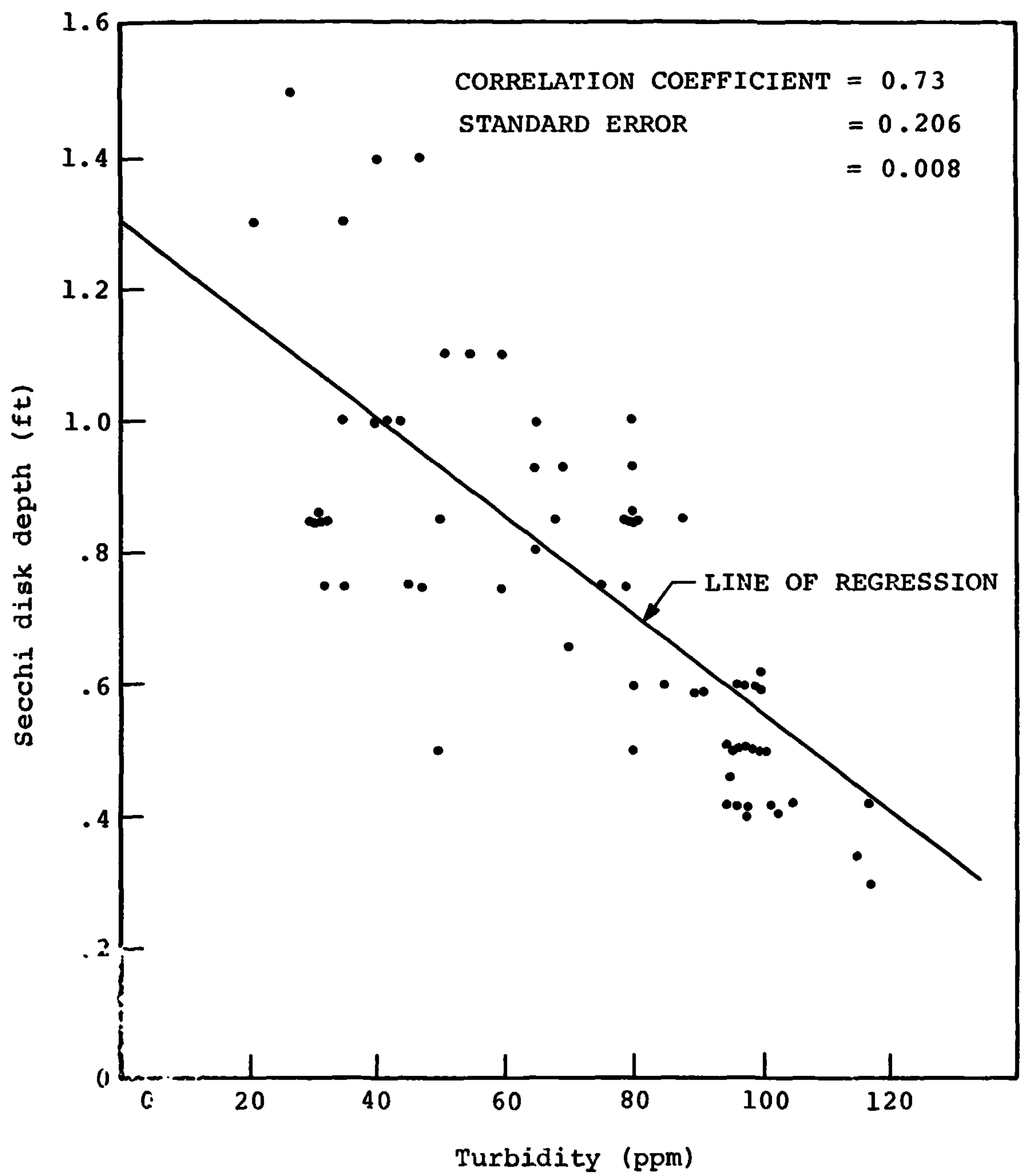


Figure A-59.– Relationship between turbidity and Secchi disk measurements.

The extinction of upwelling light for three different turbidity levels and sun angles was measured with the EXOTECH radiometer on May 8, 1973, in Trinity Bay (figures A-60 through A-62). This was achieved by submerging a 1-meter by 0.7-meter aluminum plate coated with a flat white latex paint. This target was not considered to be a Lambertian surface. The initial measurement was made while the plate was dry. Subsequent response curves (0.1, 0.25, ···, 2.0) corresponded to varying depths down to 2 feet, or to the point where the target could not be sensed. The dashed line represents the instrument response to bay water at the sampling station without the reflector.

In each case the peak transmission of upwelling light occurred in EXOTECH channel 2 (λ580 to 710 nm). Scattered light induced no instrument response in any band at depths between 1.25 and 2.25 feet, depending upon turbidity levels and sun angle. EXOTECH channel 4 (λ770 to 975 nm) attenuates at the most rapid rate, decreasing upwelling radiance by 60 to 70 percent the first 3 inches below the water's surface. Sensed effects in band 4 at depths exceeding 1 foot were negligible. Interestingly, fairly rapid attenuation occurred in EXOTECH channel 1, decreasing by 70 to 80 percent in the first 6 inches. This rate closely corresponded to that of EXOTECH channel 3, in which light attenuates at a slightly greater rate. On the basis of these observations, (1) peak penetration of solar radiation in the turbid waters of Trinity and Galveston Bays occurred in the 580- to 710-nm band and did not exceed about 2.25 feet in the clearest water, and (2) very rapid attenuation occurs within the first 6 inches in all bands.

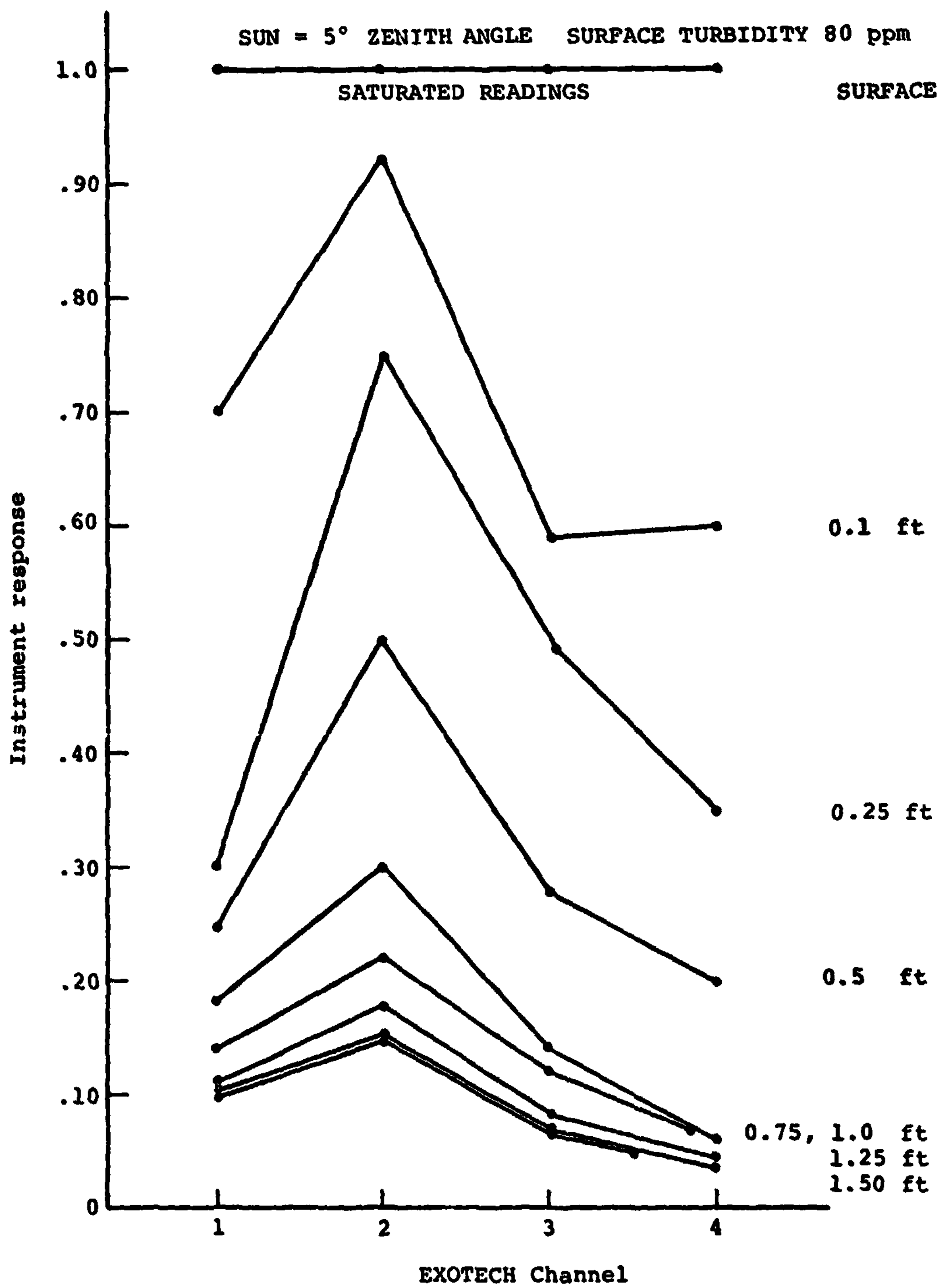


Figure A-60. - EXOTECH response to submerged disk, 80 ppm.

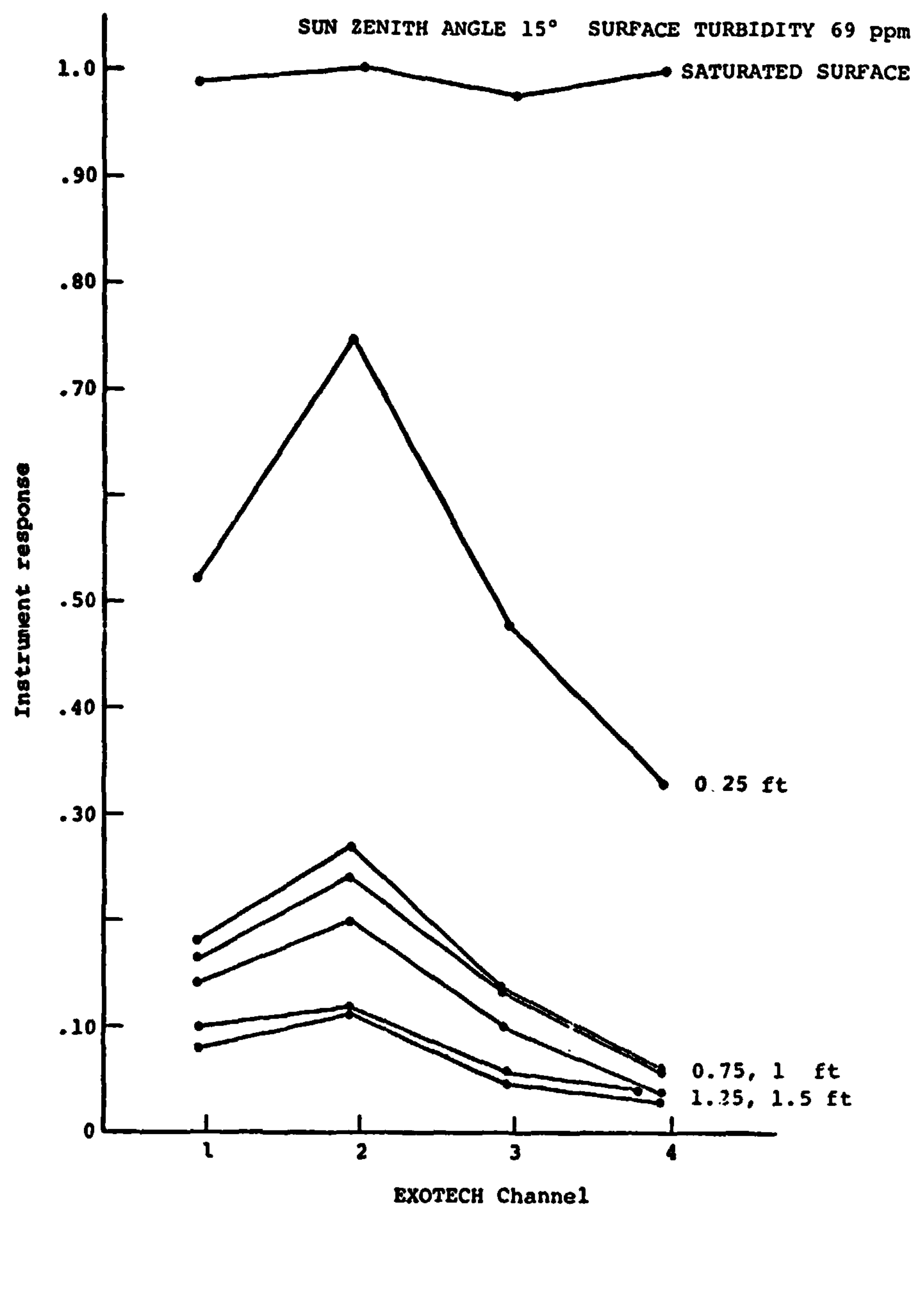


Figure A-61. - EXOTECH response to submerged disk, 69 ppm.

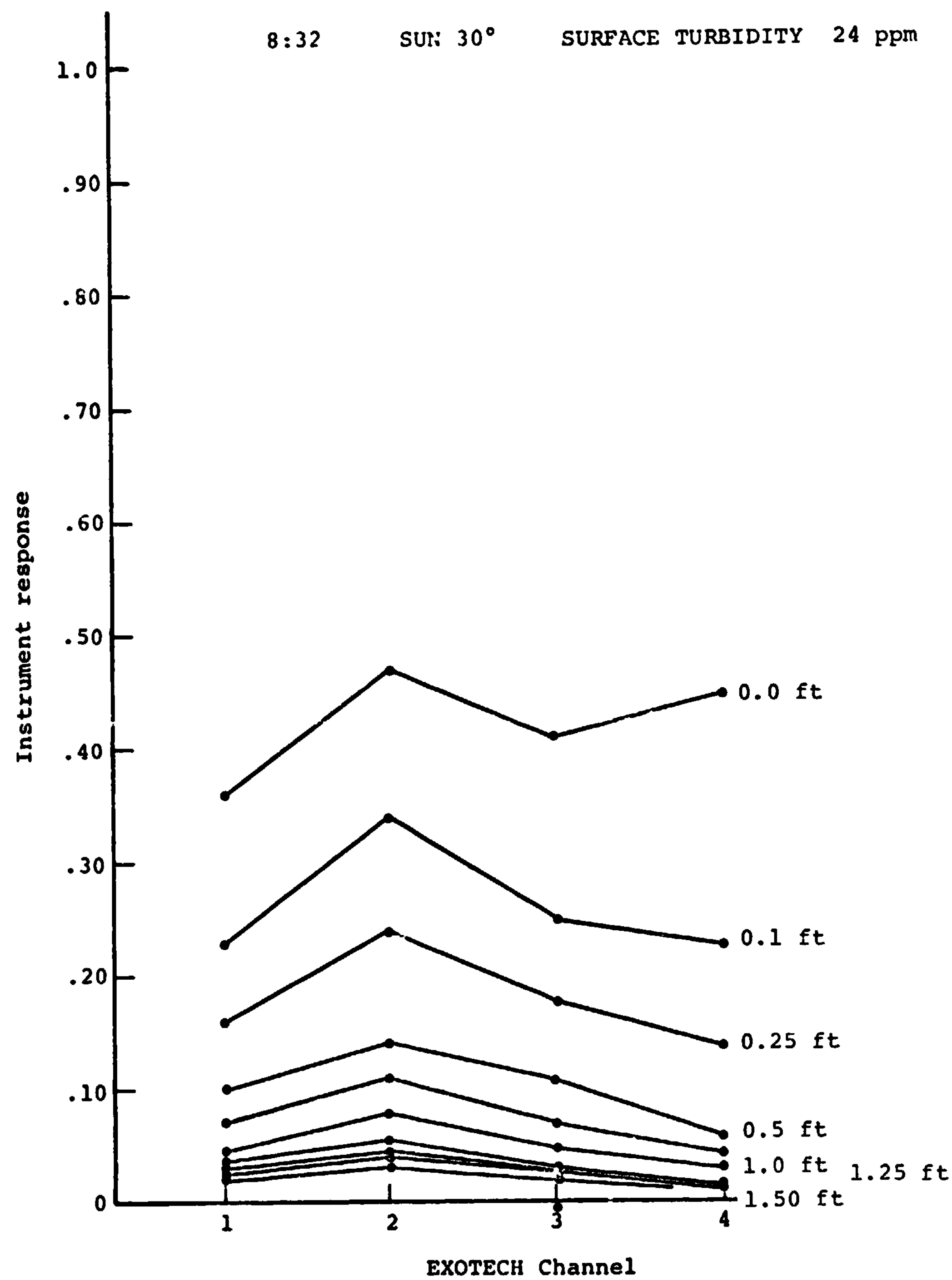


Figure A-62. - EXOTECH response to submerged disk, 24 ppm.

Both turbidity levels and sun angle induced effects on upwelling radiance. At water turbidities of 80 ppm, the water above had an average 24 percent greater reflectance in each band over the 69 ppm water; but the attenuation of light, particularly within the upper 6 inches, was nearly identical (figure A-63). The effect of zenith sun angle (0° to 60° is not readily apparent in the 69 to 80 ppm range, but becomes more apparent in a comparison between the 24 ppm and the other two data types. In the 24-ppm data, the solar zenith angle equaled 30°. At this angle the initial target irradiance was substantially less than at smaller angles. Although attenuation at 24 ppm (expressed as a percent of EXOTECH channel 5 instrument readings) was about 40 percent less than either 69 ppm or 80 ppm, the attenuation curves in figure A-65 through all turbidities and depths were very similar.

Based on the experimental results of light attenuation with depth and for the turbidities that were considered, the radiometer response is some integrated function of light scattering upward from depths not exceeding 2.25 feet. Typically, as the turbidity increases, the intensity of upwelling light increases. The measured relationship between instrument response and turbidity for Trinity Bay for 3 days is shown in figure A-64.

The EXOTECH channels 1 and 2 suggested a nearly linear instrument response to turbidity, with a smaller scatter in channel 2 (λ580 to 710 nm). In contrast, channel 3 yields a curvilinear response, which becomes more pronounced in channel 4. The range between 20 and 40 ppm in channel 4 induced essentially no change in instrument response.

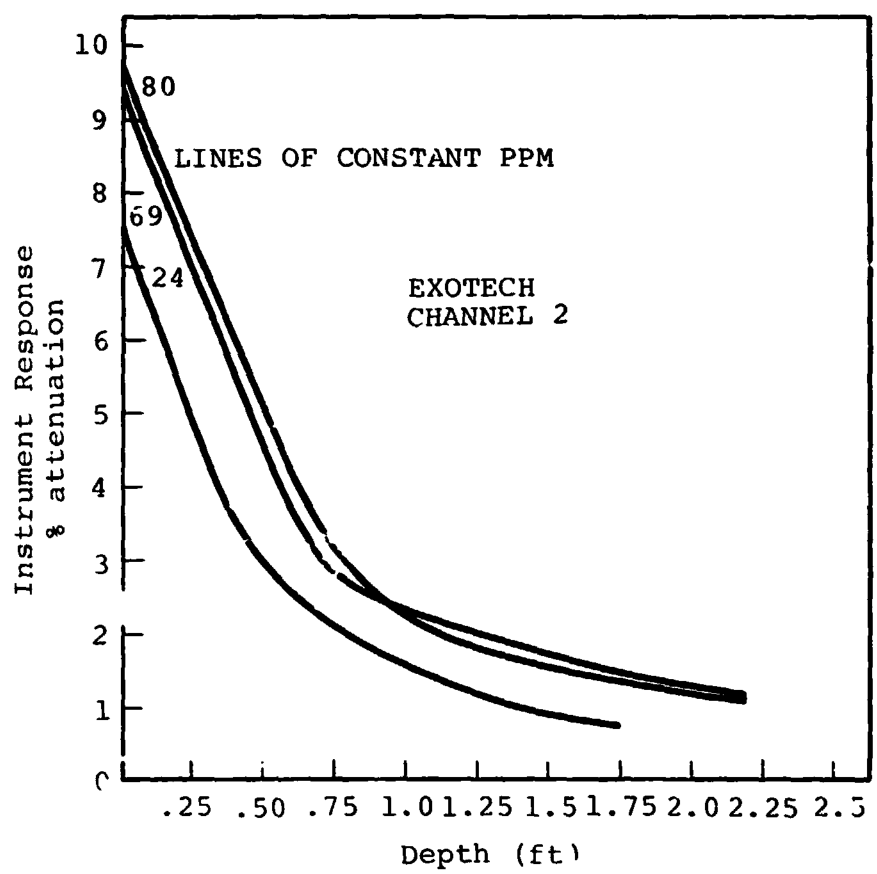


Figure A-63.– Atten ·tion of upwelling light bar at 80, , and 24 ppm.

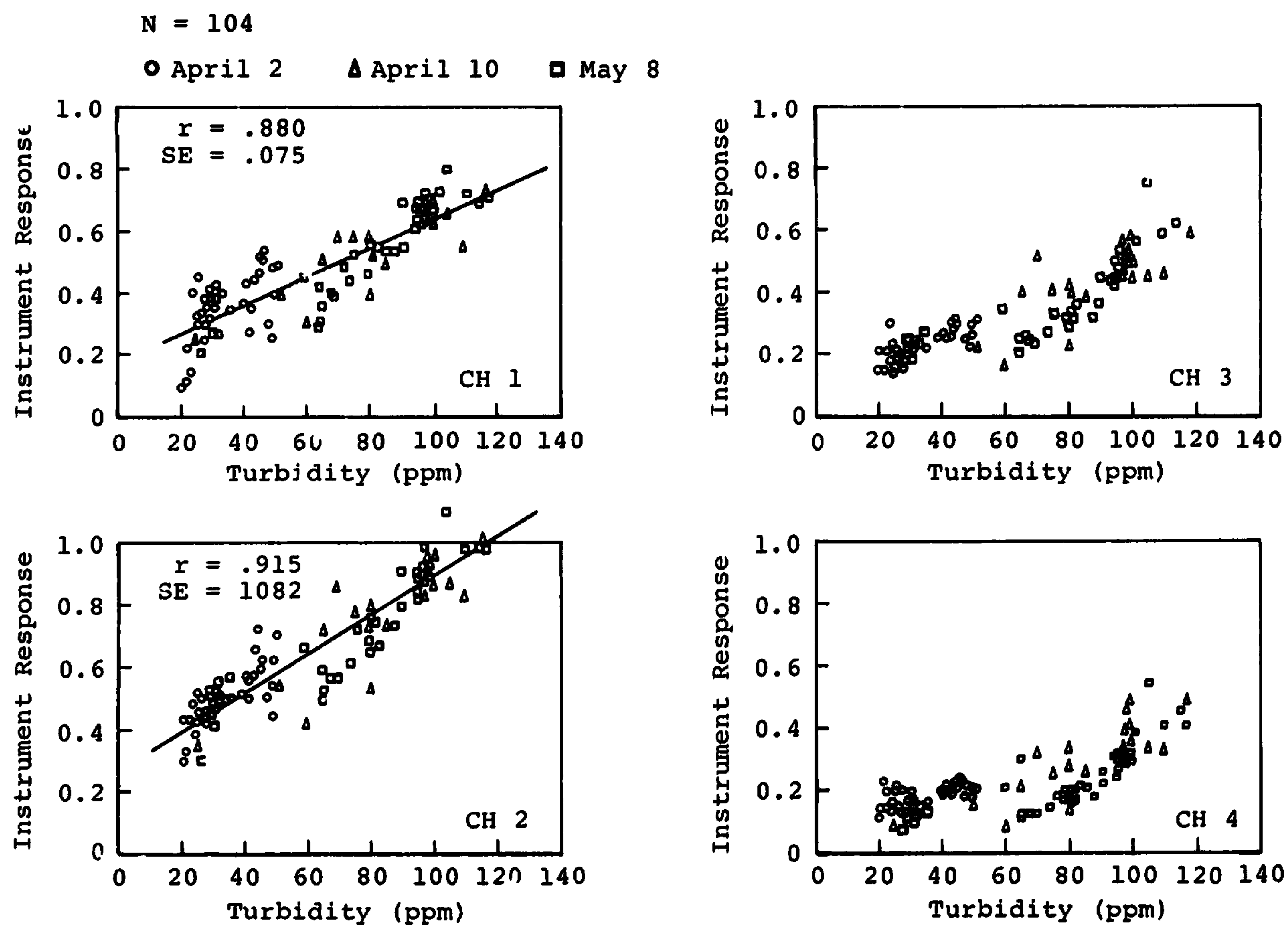


Figure A-64.— Instrument response as a function of water turbidity.

One implication of the infrared response is simply that in clear water the energy is quickly absorbed in the surface layers, but as the density of sediment approaches certain thresholds, the cumulative infrared reflectance from suspended particles exceeds the energy absorbed by the water. The integrated spectral effects of sediments at depths exceeding 9 inches is negligible, whereas at the shorter wavelengths sediments are sensed to depths ranging between 18 and 27 inches. Thus, the apparent infrared response in Trinity Bay suggests that only turbidities exceeding 40 ppm (channel 4) and 25 ppm (channel 3) induced a change in reflectivity, and that the suspended material which was sensed occurred in the upper 9 inches of the water.

The linear response and high correlations in channels 1 and 2 suggest good predictability of average turbidity in the upper 2.25 feet for the entire spectrum of turbidities between 20 and 120 ppm. Although few data points were available, there was a tendency for the line to dip steeply toward the 0-0 coordinate for turbidities below 15 or 20 ppm. Measured turbidity levels in the estuarine system rarely reached levels less than 20 ppm; however, water encountered in the Gulf commonly is in a lower turbidity range. The following linear regressions were computed for channels 1 and 2:

$$\text{CH1:} \quad \hat{Y} = .179 + .005\,X \qquad \lambda 500 \text{ to } 590 \text{ nm}$$

$$\text{CH2:} \quad \hat{Y} = .266 + .006\,X \qquad \lambda 580 \text{ to } 710 \text{ nm}$$

Neither regression has been tested against the ERTS-1 MSS response for accuracy in prediction.

Other Water Properties

Chlorophyll, temperature, dissolved oxygen, and salinity readings were taken aboard the Texas A&M vessel *Excellence*. In situ chlorophyll measurements were taken with a G. K. Turner fluorometer with a flow-through door adapted for measuring chlorophyll A. Water from a depth of 6 to 12 inches was pumped to the instruments, and water samples were taken to calibrate the readings in parts per million. Laboratory chlorophyll extractive techniques were used to determine the corrective factor, which was applied to the reading giving a chlorophyll concentration in parts per million. Chlorophyll readings were taken every 1.8 kilometers (1 n. mi.) on the ground-truth tracks (figures A-48 through A-50) on April 2, April 10, and May 8, 1973. Temperature and salinity readings were taken with in situ thermistors and inductance sensors placed in the water pumped from the surface. The readings were recorded on a strip-chart recorder, which provided a continuous record along all ground tracks for January 19, April 2, April 10, and May 8, 1973. No correlation was found between the reflectance of water in the ERTS-1 spectral bands and the chlorophyll, temperature, salinity, and dissolved oxygen in water.

APPENDIX B
MISCELLANEOUS PROCESSING PRODUCTS

The miscellaneous processing products from the computer-aided processing are presented. These products consist of JSC color composites, contrast enhancements, ISOCLS clustering maps, and LARSYS maximum-likelihood classification maps.

The JSC color composites have no definite color code for land areas; water is blue to black or dark green; sand and bare soil are generally white; and marshes are generally darker red or brown.

NASA S-73-25502

Clear water	Dark blue
Turbid water	Green or light blue
Grassland	Light orange
Forest	Dark orange

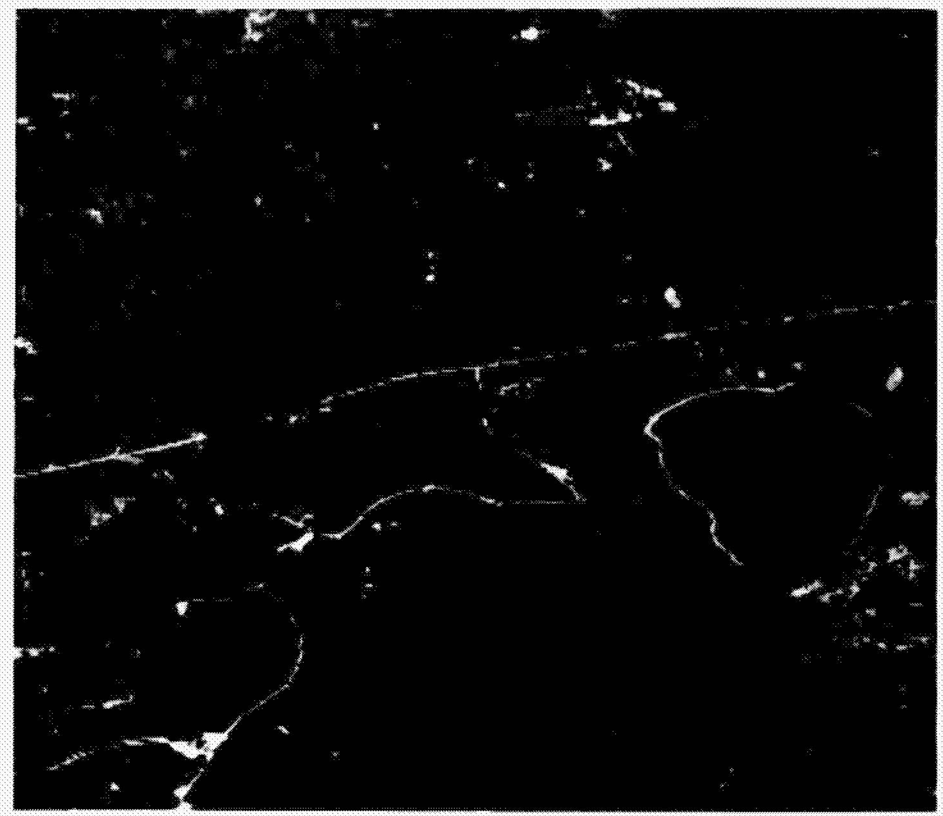


Figure B-1.— Color composite of Trinity Study Site (imagery acquired August 29, 1972, PMIS DAS, MSS bands 4, 5, and 7).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

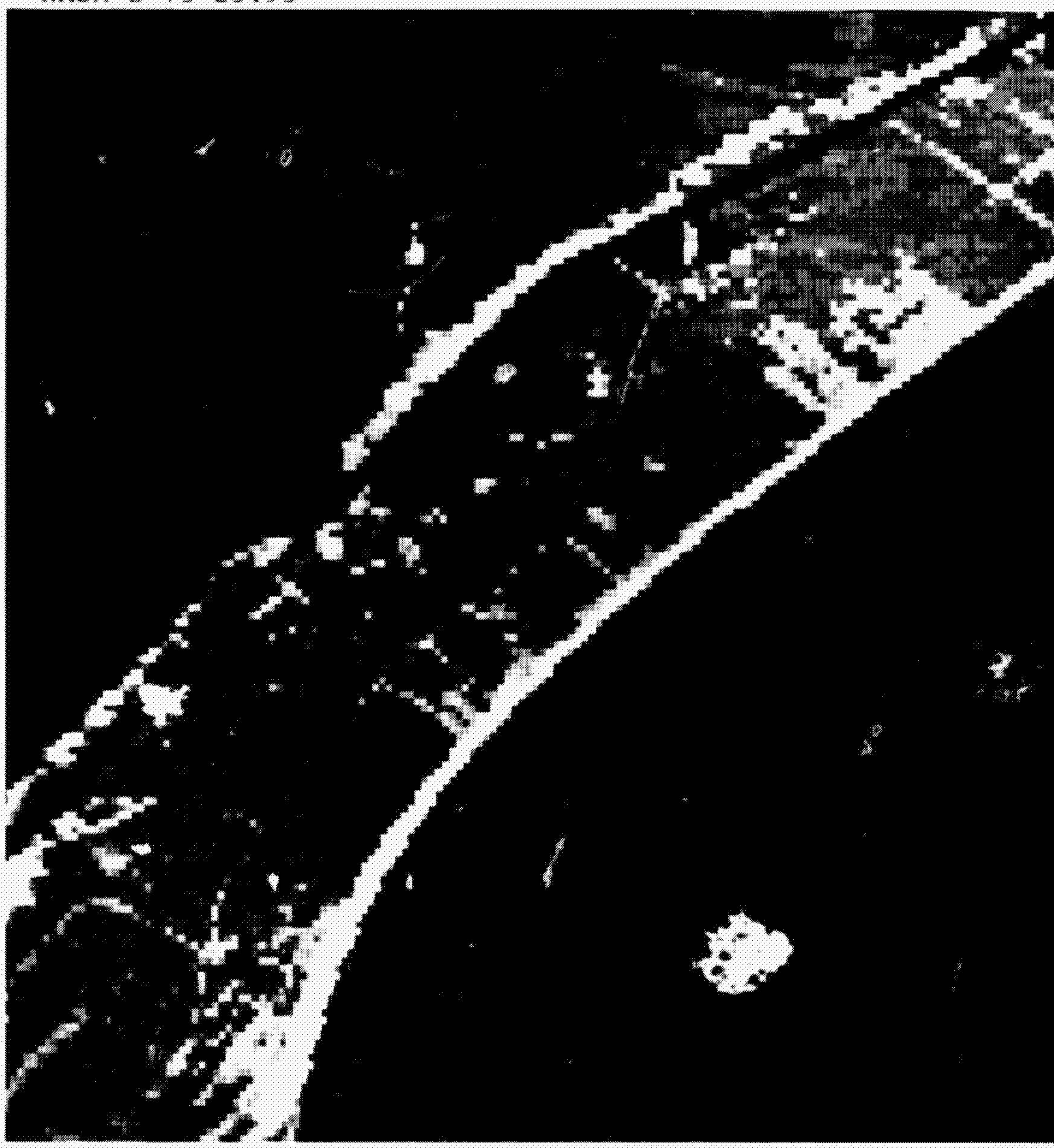
NASA S-73-25506

Clear water	Dark green
Turbid water	Light blue
Marsh (salt marsh)	Brown
Sand	White
Grassland	Orange
Urban and nonvegetated wetland	Purple

Figure B-2.– Color composite of Galveston Study Site (PMIS DAS, August 29, 1972, MSS bands 4, 5, and 7).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-25495



Water	Dark blue
Marsh	Dark orange
Sand and space	White
Grassland	Orange
Urban residential	Purple

Figure B-3.– Color composite of Bolivar Study Site (August 28, 1972, PMIS DAS, MSS bands 4, 5, and 7).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-25494 MSS4 MSS5

Figure B-4.- Contrast color enhancement of Coastal Study Area (January 19, 1972, PMIS DAS, MSS bands 4 and 5, respectively).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-25501

Water	Blue and turquoise
Wetland	Red, yellow, green, purple
Land	White

Figure B-5.– Contrast color enhancement of Bolivar Study Site (data acquired August 28, 1972, MSDS DAS, MSS band 7).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28091

Figure B-6.- Level II water cluster map of Trinity Study Site (imagery acquired October 3, 1972). See table 8-VI, page 8-25, and figure 8-7, page 8-27, for cluster identity.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28092

NASA S-73-28119

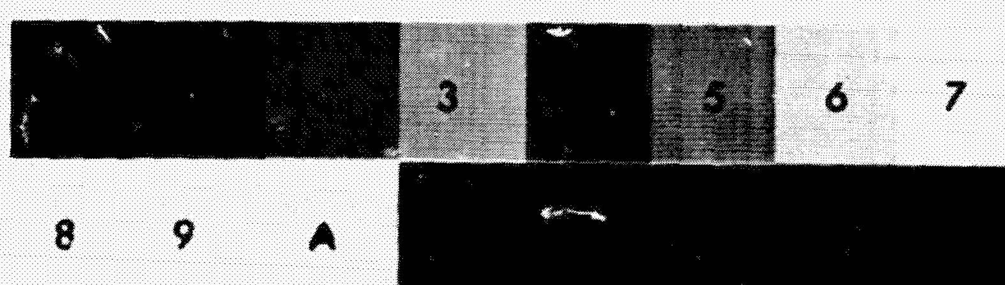


Figure B-7.- Level II water cluster map of Trinity Study Site (imagery acquired November 26, 1972). See table 8-VIII, page 8-28, and figure 8-8, page 8-30 for cluster identity.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28159

Figure B-8.- Level I cluster map of Galveston Study Site (imagery acquired August 29, 1972) For color code and cluster identity, see table 8-I, page 8-44, table 8-x, page 8-31, and figure 8-9, page 8-33.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28177

See table 8-X.

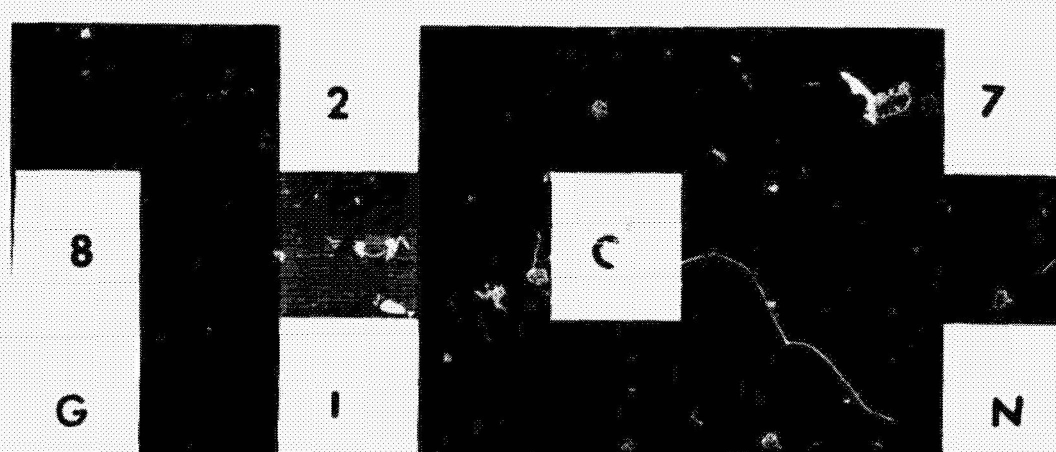


Figure B-9a.- Color code for Level III barrier flat vegetation.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28156

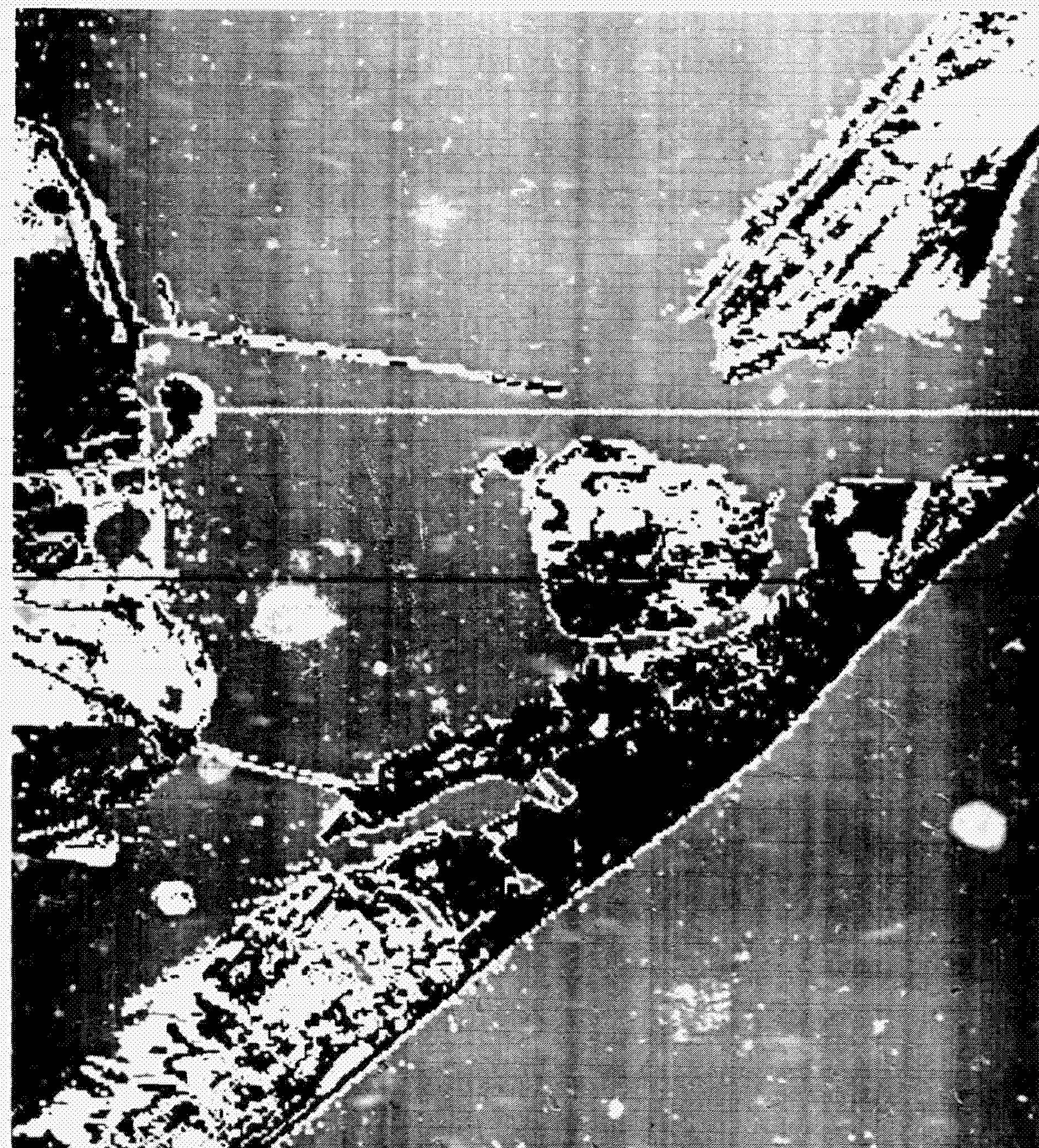


Figure B-9b.- Level III barrier flat vegetation of Galveston Study Site (imagery acquired August 29, 1972). For color code and cluster identity, see figure B-9a, page B-10, table 8-X, page 8-31, and figure 8-9, page 8-33.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28169

NASA S-73-28163

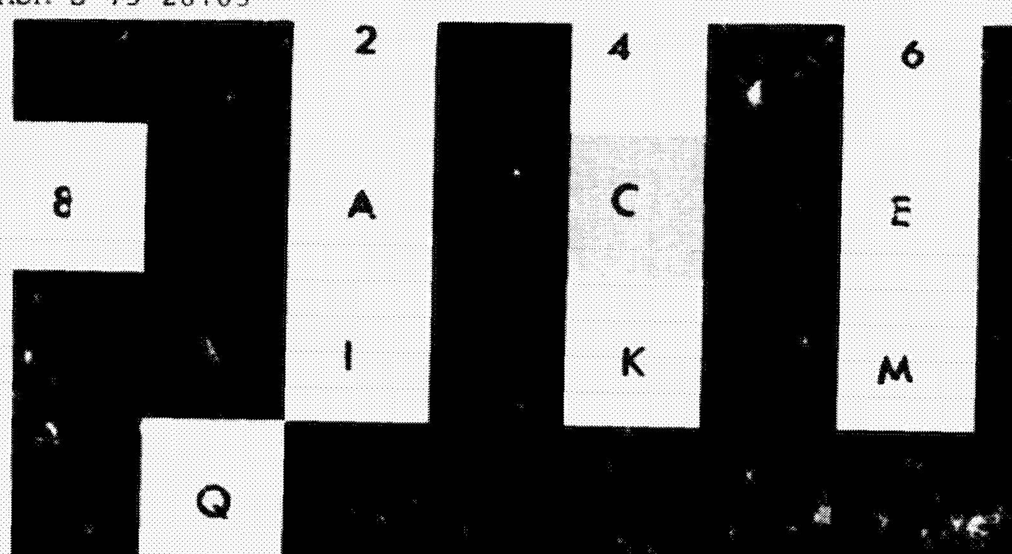
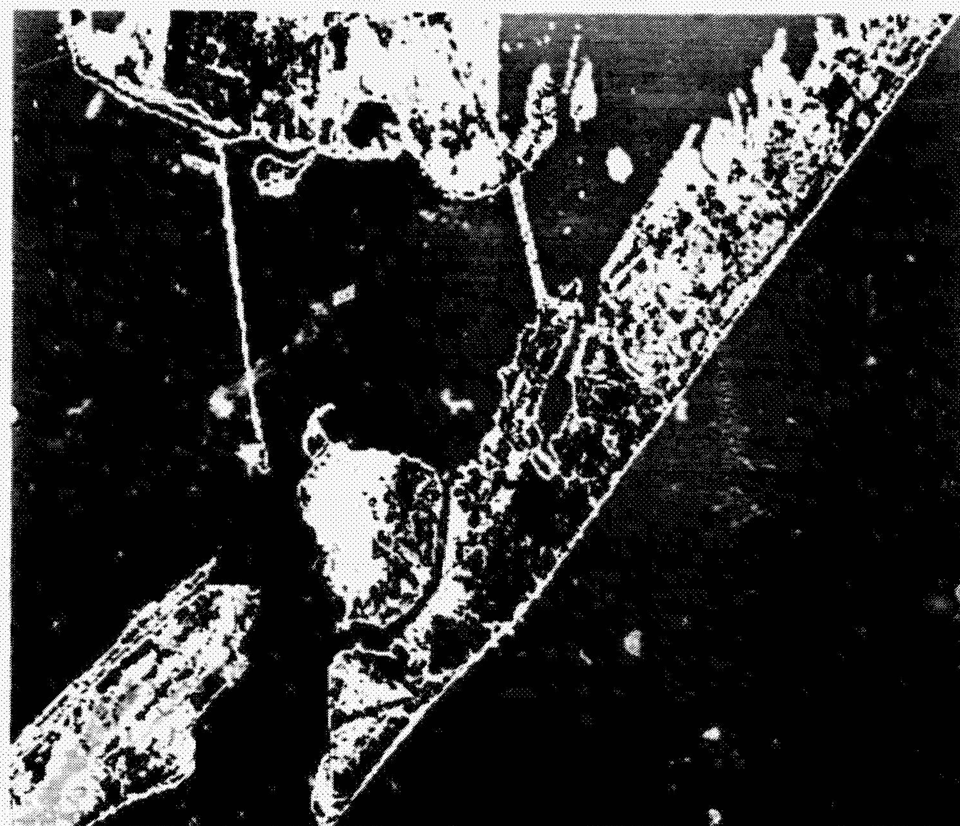


Figure B-10.- Level II water and Level I other cluster map of Galveston Study Site (data acquired October 3, 1972). For color code and cluster identity, see table 8-XII, page 8-34, and figure 8-10, page 8-36.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28165



NASA S-73-28161

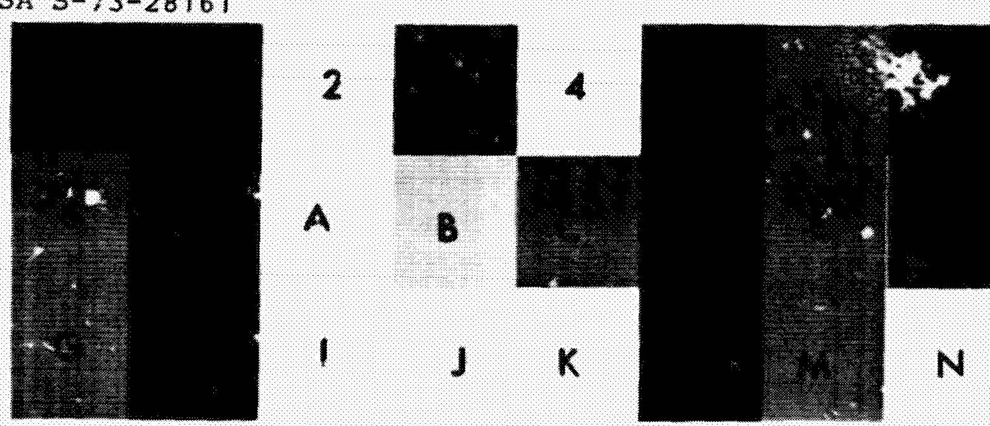


Figure B-11.- Special Level II (mirror image) cluster map of Galveston Study Site (imagery acquired October 3, 1972). For cluster symbols and identity, see table 8-XII, page 8-34, and figure 8-10, page 8-36.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28178

See table 8-XIV.

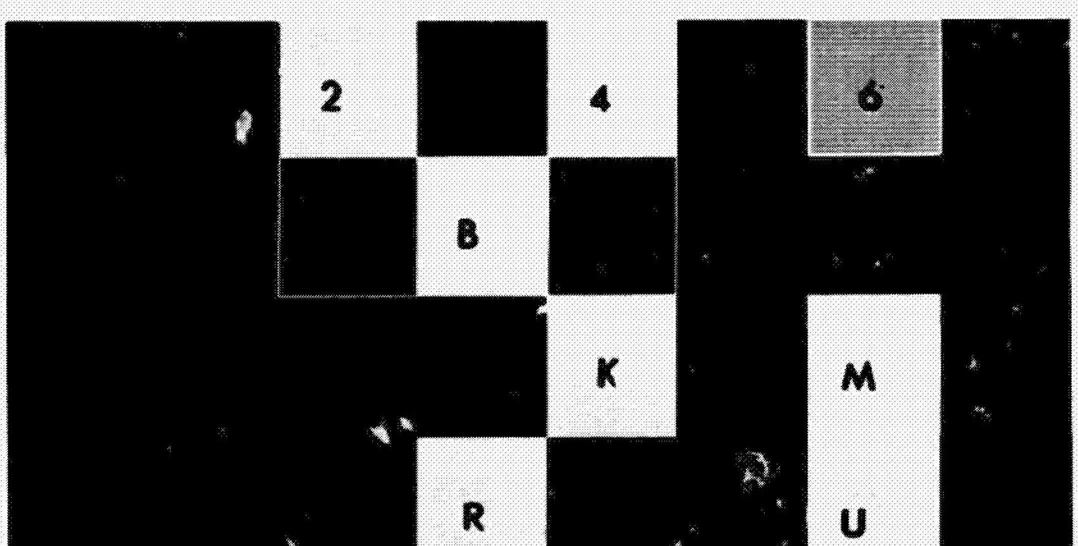


Figure B-12a.- Color code for Level II water and Level I other cluster map.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28182

Figure B-12b.- Level II water and Level I other cluster map of Galveston Study Site (imagery acquired November 26, 1972). For color code and cluster identity, see figure B-12a, page B-14, and figure B-11, page B-39.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28085

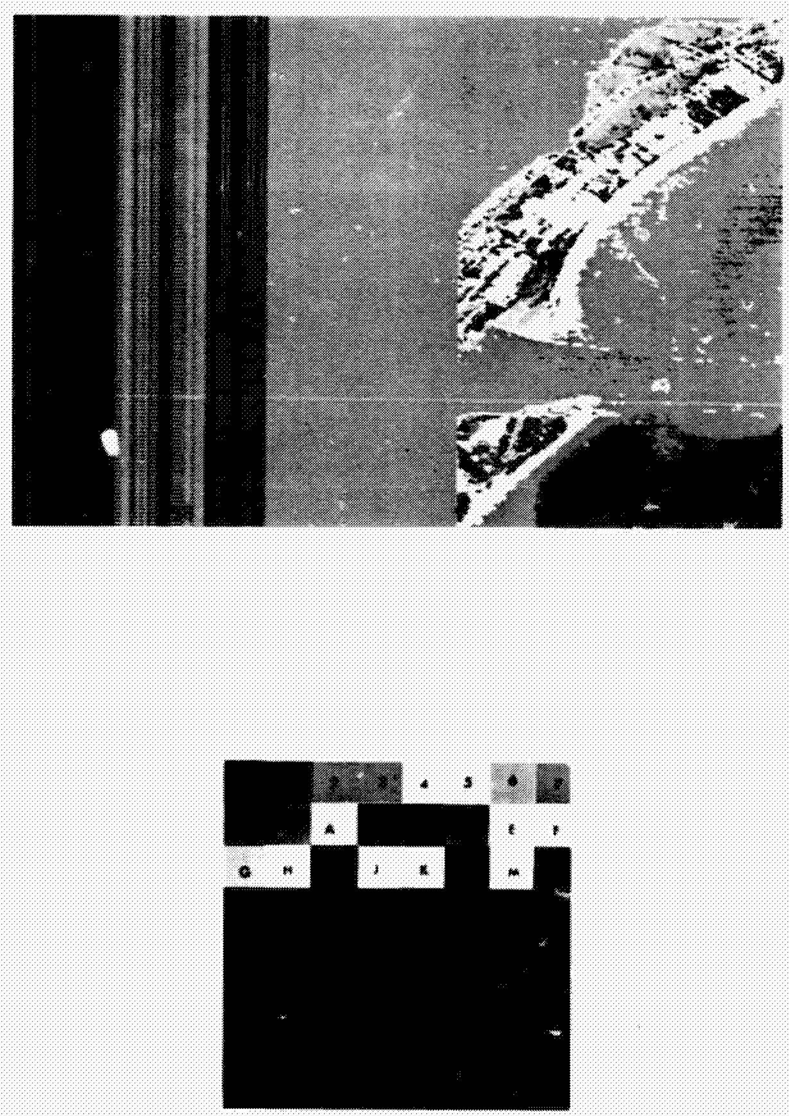


Figure B-13.- Detailed cluster map of Bolivar Study Site (imagery acquired August 28, 1972). See table 8-XVI, page 8-40, and figure 8-12, page 8-42, for cluster identity.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

NASA S-73-28093

NASA S-73-28138

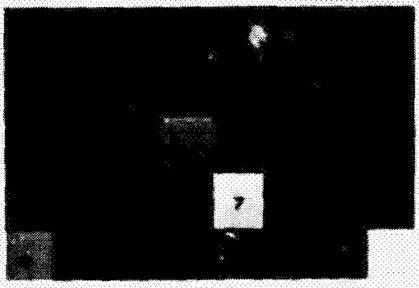


Figure B-14.- Level III wetland class map of Trinity Study Site (imagery acquired October 3, 1972). For cluster symbol and class identities, see table 8-XVIII, page 8-58, and figure 8-24, page 8-59.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.